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THESIS

EXPLOSIVE REMNANTS OF WAR-COLLECTION POINTS IN STABILITY OPERATIONS

by

Deward L. Cummings III

September 2012

Thesis Advisor:	Raymond Buettner Jr.
Second Reader:	Gregory Wilson

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13. ABSTRACT (maximum 200 words)

Explosive Remnants of War (ERW) are a global problem significantly contributing to instability throughout the undeveloped and developing-world. ERW also become a primary component used in Improvised Explosive Device (IED) fabrication across the globe, which poses a direct threat to United States (U.S.) military and its strategic partners.

Finding ERW is not the principle problem effecting stability. Safely removing and disposing of ERW in a timely manner is. In most cases, neither localized disposal capacity nor any safe and secure storage solutions exist. As a result, ERW remain a threat and hindrance to stabilization even after being discovered or collected.

This thesis demonstrates the specific design characteristics for a proposed ERW Collection Point (ERW-CP) and describes how the deployment of systems based on these characteristics can assist in mitigating the global ERW threat.

The specific characteristics that make ERW a continuous threat and hindrance to development are identified. Evidence is provided that ERW-CPs can mitigate the identified negative effects of ERW and constitute a viable option using a simple, scalable, sustainable, design and construction methodology. Data collected from empirical tests are provided to support the adequacy of the system design.

Recommendations are also provided as to how the ERW-CP design can best be disseminated to assist in strategic partner capacity building, global ERW and Counter-IED (C-IED) efforts, while adhering to global Mine/UXO awareness efforts.

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EXPLOSIVE REMNANTS OF WAR-COLLECTION POINTS IN STABILITY OPERATIONS

Deward L. Cummings III
Lieutenant, United States Navy
B.S., National Defense Intelligence College, 2007

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September 2012

Author: Deward L. Cummings III

Approved by: Dr. Raymond Buettner Jr.
Thesis Advisor

COL Gregory Wilson
Second Reader

Dr. John Arquilla
Chair, Department of Defense Analysis

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Finding ERW is not the principal problem effecting stability. Safely removing and disposing of ERW in a timely manner is. In most cases, localized disposal capacity nor any safe and secure storage solutions exist. As a result, ERW remain a threat and hindrance to stabilization even after being discovered or collected.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

ACI	American Concrete Institute
AFP	Armed Forces of the Philippines
ALP	Afghan Local Police
ANSF	Afghan National Security Forces
APM	Anti Personnel Mine
AUSA	Association of the United States Army
CCW	Convention on Conventional Weapons
CENTCOM	Central Command
C-IED	Counter Improvised Explosive Device (effort)
COTS	Commercial-Off-the-Shelf
CSIS	Center for Strategic and International Studies
CWD	Conventional Weapons Destruction
DoD	Department of Defense
DoS	Department of State
EOD	Explosive Ordnance Disposal
EODMAG	EOD Storage Magazine
ERW	Explosive Remnants of War
ERW-CP	Explosive Remnants of War—Collection Point
ESQD	Explosive Safety Quantity-Distance
FID	Foreign Internal Defense
FRBM	Fiber Reinforced Building Material
FRC	Fiber Reinforced Concrete ()
GFRC	Glass Fiber Reinforced Concrete
GICHD	Geneva International Centre for Humanitarian Demining
HA/DR	Humanitarian Aid/Disaster Relief
HCA	Humanitarian and Civic Assistance
HD	Humanitarian Demining
HD R&D	Humanitarian Demining Research and Development
HDO	Humanitarian Demining Operations
HEAF	High Explosive Application Facility
HFDR	Hazardous Fragmentation Distance Range
I.D.	Inside Diameter
IAO	International Aid Organization
ICRC	International Committee of the Red Cross
IED	Improvised Explosive Device

JFIX	Joint Interagency Field Exploration
LLNL	Lawrence Livermore National Laboratories
MCE	Maximum Credible Event
MFDR	Maximum Fragmentation Distance Range
NAWS	Naval Air Warfare Center
NFRC	Natural Fiber Reinforced Concrete
NGO	Non-Governmental Organization
NEW	Net Explosive Weight
O.D.	Outside Diameter
OASD SO/LIC	Office of the Assistant Secretary of Defense, Special Operations & Low Intensity Conflict
PAICMA	Presidential Program for Comprehensive Action against Antipersonnel Mines
PCI	Program for the Eradication of Illicit Cultivation
PET	Polyethylene Terephthalate
PM/WRA	Department of State's Office of Weapons Removal and Abatement
PNF	Processed Natural Fibers
PNFRC	Processed Natural Fiber Reinforced Concrete
PP	Polypropylene
RHA	Rice Husk Ash
RPG	Rocket Propelled Grenades
SACON	Shock Absorbing Concrete
SA/LW	Small Arms and Light Weapons
SFRC	Steel Fiber Reinforced Concrete
SNFRC	Synthetic Fiber Reinforced Concrete
SOCCENT	Special Operations Command Central
U.S.	United States
UN	United Nations
UNF	Unprocessed Natural Fibers
UXO	Unexploded Ordnance
VSO	Village Stability Operations

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LT Paul Mahoney
Mr. Vincent Carr
Mr. Jonathan Lim
Mrs. Lisa Norris
The Interns

CORE Lab:
COL Greg Wilson
Mrs. Karen Flaherty
Mr. Malcolm Mejia
LT John Taylor
LT Deak Childress
LT David Scherr
LTJG Pat Ferguson
MAJ Bert Ventura

LLNL/HEAF:
Dr. Thomas Lorenz
Mr. Ron Chambers
Mrs. Carrie Wilson

CIRPAS:
Mr. Dirk Hale
Mr. Ray Jackson

EOD:
LTJG Casey McHenry
U.S. Army 217th EOD
EODCS CJ Cowlin
CDR Jeff Morganthaler
CDR Lawrence Hall

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I. INTRODUCTION TO EXPLOSIVE REMNANTS OF WAR (ERW)

A. THE GLOBAL IMPACT OF ERW

1. ERW As a Catalyst for Instability

Unexploded (UXO) and abandoned ordnance, more broadly known as Explosive Remnants of War (ERW),[1] is a global problem with a broad range of contributing factors. ERW can be an issue in any country or region in which an armed conflict has occurred on its soil. In 2010, globally, 21,112 landmine and cluster munition civilian casualties were reported.[2]

In Afghanistan alone, over 2,000 communities (1,303,553 people) remain affected by landmines and ERW with an average of 40 Afghanis accidentally killed or injured every month by UXO.[3] Additionally, United Nations' (UN) figures state that, in 2011, nearly 1,000 civilian casualties from insurgent-placed landmine-like IEDs were intended to attack NATO troops.[4]

Aside from casualties, ERW denies local populations access to their land hindering post-conflict reconstruction and stabilization. Somalia is a prime example. With an affected population estimated at 1,340,600, the effects of ERW can be seen in almost every aspect of life. Of the affected population, 60 percent of ERW-related casualties resulted from actually handling mines or UXO.[5]

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[1] Explosive Remnants of War (ERW) according to a 2006 change to the UN Convention on Conventional Weapons (CCW) no longer covers all forms of post-conflict ordnance. The change was intended to distinguish between unexploded ordnance (UXO) and ordnance still being used, or capable of being used, such as a small arms/light weapons (SA/LW) caches, land mines, and IEDs. However, once a cache is discovered, a landmine unearthed, or ordnance removed from a disrupted or abandoned IED, it becomes ERW once again.

[2] Landmine & Cluster Munition Monitor, May 1, 2012, http://www.the-monitor.org/.

[3] E-MINE Electronic Mine Information Network, "Portfolio of Mine Action Projects 2011," *United Nations Mine Action Service*, 2, 2011, http://www.mineaction.org/downloads/1/portfoliofinal.pdf.

[4] The International Institute for Strategic Studies, ed. Alexander Nicoll, "IEDs: The Home-Made Bombs That Changed Modern War Receive Strategic," *Strategic Comments*, August 27, 2012, http://www.iiss.org/publications/strategic-comments/past-issues/volume-18-2012/august/ieds-the-home-made-bombs-that-changed-modern-war/.

[5] E-MINE Electronic Mine Information Network, "Portfolio of Mine Action Projects 2011."

Although significant, the ability to find ERW is not the principle problem effecting stability. Through numerous efforts, ERW is properly recovered everyday in regions across the globe. Unfortunately, it is also discovered and handled unintentionally on the same scale and frequency. The significant challenge remains in properly managing ERW once it has been discovered or recovered by untrained personnel.

The mismanagement of ERW allows it to remain a threat to life and limb. Mismanaged ERW are not only an immediate threat to the local population, they are a highly pilferable commodity, which leads to ERW becoming a primary component used in IED fabrication throughout the world, and as such, pose a direct threat to deployed U.S. personnel and U.S. strategic partner personnel. Additionally, ERW pose serious post-conflict humanitarian problems and remain a daily threat to populations in need of development assistance and to the humanitarian aid workers operating in these areas.

B. PURPOSE AND SIGNIFICANCE OF STUDY

The primary purpose of this research is to provide an Explosive Remnants of War—Collection Point (ERW-CP) proof of concept design that will demonstrate the unique characteristics of these collection points and to describe how they can assist in mitigating the global ERW threat. The primary purpose of this thesis is to demonstrate the specific design characteristics of ERW-CPs and how they will assist in mitigating the global ERW threat.

Specifically, this thesis identifies the specific characteristics that make ERW a continuous threat and hindrance to stabilization and development. Arguments are provided that proper ERW management through ERW-CPs can mitigate the negative effects of ERW and what constitutes an effective collection point design. Evidence collected from empirical tests is provided to support the adequacy of the design.

An ERW-CP design is described that implements a simple, scalable, design and construction methodology that utilizes locally sourced, sustainable, and reused materials. Recommendations are provided as to how the ERW-CP design can best be disseminated to assist in strategic partner capacity building and global ERW and Counter-IED (C-IED) efforts.

1. ERW and Instability

In 1980, the UN took aggressive action against the global ERW threat when it drafted the Convention on Conventional Weapons (CCW). The CCW has five protocols, two of which directly informed this thesis. Protocol II focuses on landmines, booby-traps and other devices, while Protocol V focuses on the global problem of ERW.

Under Protocol V, state or non-state actors involved in an armed conflict are required to take action to clear, remove or destroy ERW, and record, retain and transmit information related to the use or abandonment of explosive ordnances. They are also obligated to take all feasible precautions for the protection of civilians and humanitarian missions and organizations. Conflict participants, in a position to do so, should provide cooperation and assistance for marking, clearance, removal, destruction, and victim assistance, amongst other things.[6] Since the drafting of the CCW, the United States has had a standing commitment to dealing with ERW. However, some deficiencies are present in the U.S.'s ability to empower partner nation populations in the safe and secure management of ERW.

The goal of this thesis is to demonstrate the potential effectiveness and cost benefit of the ERW-CP proposed design and describe how it may be deployed to address ERW management problems.

C. MAJOR RESEARCH QUESTION & NESTED QUESTIONS

1. Managing ERW Effectively

This thesis addresses the utility and implementation of ERW-CPs. First, what would be the practical benefit of effective ERW management for the United States and its strategic partners in stability operations? While many strategic partner countries have pursued robust ERW disposal and mine action programs as part of larger stability efforts, a significant gap still exists in ERW management capabilities. It is hypothesized that

[6] E-MINE Electronic Mine Information Network, "Convention on Certain Conventional Weapons–Protocols II and V," October 2006, http://mineaction.org/overview.asp?o=1117.

effective ERW management for U.S. partners will fill a gap in the ERW mitigation process and give the United States, its partners, and potential strategic partners another tool to increase regional stability.

This thesis also focuses on the ERW-CP design proof of concept, which requires empirical data demonstrating the effectiveness of ERW-CPs based on design requirements. Additionally, it compares the cost and benefits of ERW-CPs against traditional ERW storage efforts, and provides positive crosslinks to larger U.S. national priority efforts and strategic partner capacity and stabilization efforts.

The research results demonstrate the effectiveness of the ERW-CP design and provide the basis for a bottom up implementation plan that will aid U.S. forces and strategic partners conducting post conflict reconstruction and stabilization efforts; all of which must be accomplished while adhering to UN CCW protocols and Mine/UXO awareness programs.

II. DEFINING THE PROBLEM

A. OVERVIEW

1. Organization and Execution

ERW, according to a 2006 change to the UN CCW, no longer covers all forms of post-conflict ordnance. The change was intended to distinguish between UXO and ordnance still being used, or capable of being used, such as a weapons cache, land mines, cluster munitions and IEDs. However, once a usable item or cache is discovered, a landmine unearthed, or ordnance removed from a disrupted or abandoned IED, it becomes ERW once again. As such, this thesis groups all instances into the generalized term ERW or ERW problem.

To grasp the scope of the global ERW problem and its effect on stability, it is necessary to look no further than the numerous internationally recognized organizations that distribute publications and maintain websites focused specifically on the subject.

A suitable starting point is the U.S. Department of State's "To Walk the Earth in Safety: The United States' Commitment to Conventional Weapons Destruction." This study covers all aspects of the global ERW, landmine problem and has combined the issues into one, Conventional Weapons Destruction (CWD). Like most studies of this nature, it is broken down by region: Africa, Asia, Europe, Latin America, and the Middle East. The study breaks the regions down even further by countries and examines each country's individual variables contributing to the problem.[7]

The UN provides a similar study on an annual basis entitled "Portfolio of Mine Action Projects 2011,"[8] as do many other organizations, such as the International Committee of the Red Cross (ICRC) and numerous privately funded Non-Governmental

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[7] U.S. Department of State, Bureau of Political-Military Affairs, "To Walk the Earth in Safety: The United States' Commitment to Conventional Weapons Destruction," 9th ed., July 2010.

[8] E-MINE Electronic Mine Information Network, "Convention on Certain Conventional Weapons–Protocols II and V."

Organizations (NGOs). Additionally, several organizations have developed task frameworks to aid in understanding instability variables, which often focus on issues such as ERW.

B. FINDINGS

1. Conceptual Literature

While the literature indicates various causes of ERW problems in various geographic areas, it remains largely descriptive. Generally, this body of work provides the scope and scale of the ERW problem by country and the efforts being taken to mitigate the presence of ERW. While various approaches to the ERW problem are discussed in terms of locating and then disposing of ERW, sufficient work on prescriptive measures to reduce instability stemming from ERW substantially does not exist. Also, not readily available is a locally derived and sustainable solution for temporarily storing and securing ERW awaiting disposal. This problem can be linked to a wide variety of related topics: Foreign Internal Defense (FID), Village Stability Operations (VSO), Humanitarian Demining Operations (HDO), Humanitarian Aid/Disaster Relief (HA/DR) and the global C-IED effort. Although the literature addresses most of these concepts and explains how these separate elements and efforts are intended to work in concert to achieve regional stability successfully, very rarely do they provide singular examples that incorporate all or most of the aspects. This thesis reviews differing scales of the ERW management deficiency selected from several studies.

The ERW management gap is caused by the relationship between the scale of ERW contamination and the available ERW management capacity and limitations. It is well established that ERW is a global problem. However, each country or region has specific variables that contribute to issues of ERW management within that country or region.

The main issues concerning the management of ERW can be explained by viewing all the commonly understood variables in post-conflict reconstruction and stabilization efforts. The common structure for tackling the post-conflict environment is a task framework. Most frameworks are organized into three conceptual phases: initial

response, transformation, and fostering sustainability. The framework tasks are usually organized into pillars, such as security, justice/reconciliation, social/economic well being, and governance/participation. The pillars are inherently interconnected and arguably, success in one is usually dependent on success in another, but they are not necessarily sequential.[9]

Most security pillars specifically cite disarmament as one of the key variables in reconstruction and stability operations. In these frameworks, disarmament usually falls under a Small Arms and Light Weapons (SA/LW) provision requiring the securing, storing, and disposing of weapons and ammunition while indigenous arms control capacity is developed. Additionally, ERW issues are usually addressed under a UXO provision. The post-conflict reconstruction task framework presented by the Center for Strategic and International Studies (CSIS) and the Association of the United States Army (AUSA)[10] is an excellent point of reference when breaking down post-conflict reconstruction and stabilization efforts.

In 2005, the U.S. Department of State (DoS) adopted the CSIS model and published a very similar framework. The DoS and CSIS frameworks are almost identical concerning security and dealing with the ERW problem and their effect on stability operations.[11] The UN, while it does not have a single framework, has a myriad of publications and websites concerning all aspects of post conflict and stability operations. Although the UN frameworks are country specific, they largely consist of national policy suggestions and rarely enter into details.

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[9] U.S. Department of State, Office of the Coordinator for Reconstruction and Stabilization, "Post Conflict Reconstruction Essentials Tasks," April 2005.

[10] Center for Strategic and International Studies and Association of the United States Army, "Post-Conflict Reconstruction Task Framework Report," May 2002, http://csis.org/files/media/csis/pubs/framework.pdf.

[11] U.S. Department of State, Office of the Coordinator for Reconstruction and Stabilization, "Post Conflict Reconstruction Essentials Tasks."

Taken together, these frameworks demonstrate the need for proper ERW and SA/LW management as a key variable in the success of post-conflict reconstruction and stability operations. However, they are just frameworks and do not delineate the exact requirements best suited for such operations and the unique variables inherent to individual countries and regions in these situations.

In conjunction with framing the global ERW problem, significant efforts have been made to educate affected populations properly on the dangers of ERW, and landmines. The United States, through the Department of State's Office of Weapons Removal and Abatement (PM/WRA) in partnership with the Department of Defense's Humanitarian Demining Research and Development (HD R&D) Program, attempts to solve the ERW problem by aiding its strategic partners in educating populations on the dangers of ERW. This effort is in concert with international programs, such as the UN's Mine/UXO awareness program. Most notably, the "Don't touch it, mark it and report it" campaign.[12]

The efforts to educate ERW affected populations, while idealistic, must not be ignored. The "Don't touch it, mark it, report it" campaign concentrates on teaching local populations to properly identify, but not handle, ERW under any circumstance.[13] This viewpoint may seem contradictory to the concept of a locally managed ERW collection point, if the global awareness effort is focused on not handling ERW. Inherently, ERW will be handled for it to be collected. However, an ERW-CP is only needed when no reliable reporting system exists above the local authority or, even when reported, the capacity to dispose of the ERW in a timely manner is not available. To be effective, the ERW-CP project should adhere to global Mine/UXO awareness program efforts based on the stabilization task frameworks.

In addition to task frameworks, project profiles are used to reference and frame the ERW problem to prioritize efforts. Works cited earlier, such as the U.S. Department of States' "To Walk the Earth in Safety: The United States' Commitment to Conventional

[12] United Nations, "International Guidelines for Landmine and Unexploded Ordnance Awareness Education," (n.d.), http://www.mineaction.org/downloads/mineawar.pdf.

[13] Ibid.

Weapons Destruction,"[14] and CWD[15] provide such profiles, as do the UN and many other NGOs on an annual basis that cover all the affected regions of the globe.[16]

2. Efforts, Profiles and Examples

In addition to studies and educational programs, the United States provides direct assistance to its partners in finding and disposing of the maximum amount of ERW possible. Military Explosive Ordnance Disposal (EOD) teams regularly conduct multilateral ERW disposal operations around the world. To give an example of the magnitude of the ERW challenge, during the 2009 iteration of the annual Balikatan exercise, U.S. Navy EOD and their Armed Forces of the Philippines (AFP) counterparts disposed of over 346,500 lbs. of ERW in the southern Philippines alone.[17]

Unfortunately, ERW and demining programs are often limited in their reach into isolated areas, and the United States cannot dispose of all ERW simultaneously all over the world. As a result, ERW requires storage at the locally isolated level. Lack of, or ineffective storage facilities for ERW awaiting disposal, can substantially affect ERW-related instability.

Under Colombia's Program for the Eradication of Illicit Cultivation (PCI), the government employs manual coca eradicators to destroy fields of illegal crops. These eradicators are usually young peasants from impoverished regions who receive little to no training prior to eradication operations. Consequently, 47% of Colombian landmine victims in 2010 were coca eradicators. As of May 2011, the Presidential Program for Comprehensive Action against Antipersonnel Mines (PAICMA) and PCI reported 14 victims of antipersonnel mines (APM) directly linked to manual eradication.[18]

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[14] U.S. Department of State, Bureau of Political-Military Affairs, "To Walk the Earth in Safety: The United States' Commitment to Conventional Weapons Destruction."

[15] Ibid.

[16] E-MINE Electronic Mine Information Network, "Portfolio of Mine Action Projects 2011."

[17] Neptunus Rex, "Operation: Flashpoint," ed. Naval Special Operatoions Group Philippine Fleet, The Tridnet, *Naval Special Operatoions Group Philippine Fleet*, Second Quarter 2011, no. EOD Issue (April-July 2011): 10.

[18] Colombia Reports, "Colombia's Civilian Coca-eradicators Violate Landmine Treaty," July 22, 2011, http://colombiareports.com/opinion/157-guests/17810-civilian-deaths-authorized-by-government-as-part-of-anti-drug-measures.html.

However, these numbers are most likely inaccurate. Indigenous populations may be reluctant to cooperate fully with demining efforts as Colombian military forces conduct the bulk of demining operations.[19]

An unfortunate result is the Colombian government may be at risk of violating Article 5 of the Ottawa Treaty by sending uneducated civilians into mined areas without adequate mine awareness training. Article 5 states:

> Each State Party shall make every effort to identify all areas under its jurisdiction or control in which anti-personnel mines are known or suspected to be emplaced and shall ensure as soon as possible that all anti-personnel mines in mined areas under its jurisdiction or control are perimeter-marked, monitored and protected by fencing or other means, to ensure the effective exclusion of civilians, until all anti-personnel mines contained therein have been destroyed.[20]

In Colombia's defense, the above-described programs operating under the frameworks do provide available demining capability to support these operations, but these efforts continually fall short of the overwhelming need, which unfortunately, leads to unofficial programs functioning out of necessity that do not fall under any frameworks.

Village demining activities are becoming more and more frequent. Local populations who do not have formal training and who do not have access to the proper demining equipment are executing demining out of necessity. According to organizations, such as UNICEF, OCHA, the EU, Landmines Observatory, and the Colombian Campaign Against Landmines, these activities are occurring both individually and in groups.

Unfortunately, these efforts only begin to address the full regional scope of landmine contamination or the ERW problem in Colombia. To compound the problem, once these unofficial demining operations have cleared an area, the locals have no way to dispose of the ERW. ERW, whether conventional or improvised, rapidly deteriorates over

[19] Geneva Call, "Mine Action in the Midst of Internal Conflict," ed. Elisabeth Reusse-Decrey Matthew Pountney, September 1, 2006, http://www.isn.ethz.ch/isn/Digital-Library/Publications/Detail/?id=38542&lng=en.

[20] United Nations, "Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on Their Destruction," September 19, 1997, http://www.un.org/Depts/mine/UNDocs/ban_trty.htm.

time and becomes increasingly unstable the longer it is exposed to environments, such as the humid jungles of Colombia. Obviously, all parties involved would like to locate, remove or render safe, and dispose of all landmine and ERW contamination. However, even if Colombia received unlimited support, it could not dispose of everything simultaneously throughout the region. As a result, the inability to store ERW awaiting disposal, yet again, substantially affects stability.

Having no disposal options, the local village demining effort, and often official demining operations, attempt to provide secure storage on their own. In the environments in which most demining occurs, suitable and secure protective structures are not available nor can they be locally constructed, which is another example of the ERW management gap represented in storage shortfalls.

ERW storage is not a new issue. Since the end of WWII, significant work has been done to remove and dispose of unstable and UXO. However, most of the solutions and techniques developed to manage ERW properly are unrealistic for most of the undeveloped and developing world, which suffers the most from the ERW problem. In 2002, the Geneva International Centre for Humanitarian Demining published a report describing the hazards associated with the mismanagement of ERW, and cited over 70 catastrophic incidents. From 1990 to 2002, 31 reported (official) ammunition storage area incidents occurred in post-conflict environments, and 39 incidents in non-conflict environments resulted in 2,461+ casualties. Over half these incidents were not reported, or did not have an accurate report done for the Net Explosive Weight (NEW) of the incident. For the 23 incidents that were reported, the estimated NEW totaled over 33,203 tons.[21]

Unfortunately, these statistics only cover large facilities that could not easily go unnoticed. The report excludes the hundreds of active SA/LW caches, and small improvised ERW storage facilities that unintentionally detonate every year that kill and

[21] The Geneva International Centre for Humanitarian Demining, ed. Jack Glattbach, "Explosive Remnants of War (ERW)–Undesired Explosive Events in Ammunition Storage Areas," *International Relations and Security Network*, 36–38, 2002, http://www.isn.ethz.ch/isn/Digital-Library/Publications/Detail/?ots591=0c54e3b3-1e9c-be1e-2c24-a6a8c7060233&lng=en&id=26686.

injure hundreds.[22] In 2003, the United Nations Development Programme estimated that in West Africa alone, an estimated eight million illicit small arms and light weapons exited. These weapons range from the common AK-47 and rocket propelled grenades (RPG) to truck mounted small caliber artillery.[23] All these weapons, even when recovered and taken out of circulation, require improvised storage facilities for their ammunition. If not secured properly, the ammunition finds its way back into circulation or into the IED cycle. If secured but stored improperly, the storage points become as real a threat as their larger NEW brethren. This entire situation is cited as one of the main contributing factor to instability in the region.[24]

C. SUMMARY

1. Current Global ERW Management Solutions

The continuous ERW management gap is caused by the relationship between ERW global management mandates and country or regional ERW management limitations. It is well established that ERW is a global problem. However, each country or region has specific variables that contribute to issues of ERW mismanagement within that country or region.

Despite the tremendous efforts to educate affected populations about the hazards of ERW and landmines, Mine/UXO awareness programs still fall short of reality. The mantra "Don't touch it, mark it, report it"[25] is dependent on a system to report "it" to, and the knowledge or hope that someone is capable of conducting disposal operations once the report is received. Unfortunately, this situation is often not the reality, as is the case in Columbia and many other regions.

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[22] John Borrie, "Explosive Remnants of War a Global Survey," ed. Rosy Cave and Richard Lloyd, *Landmine Action*, 2003, http://www.unidir.org/pdf/activites/pdf-act287.pdf.

[23] *ECOWAS Small Arms Control Programme (ECOSAP). Programme to Tackle the Illicit Proliferation of Small Arms and Light Weapons in ECOWAS States*, United Nations Development Programme (New York: United Nations, 2003), 3.

[24] Ibid.

[25] United Nations, "International Guidelines for Landmine and Unexploded Ordnance Awareness Education."

Traditional "First World" ERW management approaches are idealistic at best. Often times, the guidance is vague or so restrictive, it becomes unrealistic. Rarely does a guide describe the actual facilities in which ERW or SA/LW should be secured or stored.[26] In their defense, a certain level of understanding exists that these guides are just that, guides to best practices and are to be followed to the appropriate levels. Unfortunately, this sentiment often leads to improvised structures constructed of sandbags and or used tires that do not provide adequate protection to the populace from ERW, nor do they protect the ERW from further deterioration from the elements. In most situations, a result of lack of access is the cause. At the low end of the spectrum, simply digging a deep enough hole for ERW storage in every village affected by ERW does not provide an adequate solution. At the opposite end of the spectrum, building military grade facilities is infeasible. In developing parts of the world, it is very rare to find a population that has access to suitable construction technologies required to construct first world solutions, e.g., large reinforced concrete structures. They rely on donor funding and are forced to contract out the work. This way of doing business is unrealistic in most cases, unsustainable on a large scale, and does not address the true scope of the ERW problem.

While it is admirable that efforts are made to make improvised protective structures, they often cause more harm then good. When makeshift ERW storage facilities are constructed, they can foster a false sense of security. They are often immediately overstocked with ERW, which renders what little if any, protection they originally offered.

An appropriate, and sustainable ERW management solution is immediately required at the lowest levels that is simple, scalable and in line with UN CCW protocols and Mine/UXO awareness programs. Additionally, as national and international ERW disposal efforts expand to reach previously isolated ERW affected populations, the desired ERW management solution should facilitate recording, collation and disposal

[26] The Geneva International Centre for Humanitarian Demining (GICHD), "Publications: A Guide to Ammunition Storage," November 2008, http://www.gichd.org/fileadmin/pdf/publications/Ammunition-Storage-2008.pdf.

operation prioritization, which in turn, will greatly diminish the need for costly and time-consuming UN mandated ERW and landmine surveys required to move disposal efforts forward.[27]

[27] United Nations, " International Guidelines for Landmine and Unexploded Ordnance Awareness Education," 1.

III. DESIGN REQUIREMENTS

A. SYSTEM REQUIREMENTS BASED ON CURRENT DEFICIENCY

1. What Is Required?

A system or structure is required that provides safe, secure, temporary storage of ERW at the village level. The system or structure must be scalable, readily available, and once constructed, clearly marked and easily accessible to the local ERW affected population. The system or structure must provide an acceptable level of security to prevent theft of the stored ERW. The system or structure must be easily constructed by affected populations using locally sourced building materials at little to no cost to the local population.

2. What Function Must Be Accomplished?

a. Primary

Provide secure storage for ERW items or abandon IEDs to prevent the ERW from entering into the IED network, or the abandoned IED from reentering the IED cycle. Also, when exposed to harsh climates, or repeated swings in temperature, the exterior ERW casings rust and internal explosive chemical compounds are drastically sensitized, which makes the ERW susceptible to unintended detonation. Inherently, providing secure storage will protect the ERW from the elements, and prevent further deterioration.

b. Secondary

In the event of an unintended ERW or abandon IED detonation, the structure must stop all ordnance-produced primary fragmentation,[28] while eliminating or creating minimal secondary fragmentation[29] from the structure itself or the surrounding area.[30]

The system or structure should redirect the thermal effects and blast overpressure wave away from the population and mitigate its effects as close as possible to a K-Factor of 24. A K-Factor of 24 or K-24 (31 ft. or 9 m) is the minimum distance allowed between an individual and an l lb. TNT equivalent explosive detonation without receiving life threatening or disabling injuries, such as lung or ear drum ruptures.[31] As per Department of Defense (DoD) Ammunition and Explosives Safety Standards Manual (6055.9-STD), personnel protection must limit incident blast overpressure to 2.3 psi (15.9 kPa).[32]

3. What Must Be Accomplished To Completely Alleviate The Deficiency?

To alleviate the effects of an unintended item detonation completely, the structure must completely stop all ordnance-produced fragmentation without creating any secondary fragmentation from the structure itself or the surrounding area. The system or structure should completely redirect the thermal effects and blast overpressure wave away from the population to mitigate its effects to a maximum K factor of 24 (24 ft). The structure must also completely secure the ERW from theft. While these parameters are

[28] Primary fragmentation results from the shattering of the ordnance item vessel, such as shell casings or other containers used in the manufacture of ordnance or IEDs. Primary fragments are usually small, and initially travel at thousands of feet per second, and remain lethal for long distances.

[29] Secondary fragmentation is usually debris picked up by the explosion from the surrounding area that has an impact energy of 58 ft-lb. or greater.

[30] Department of Defense, Under Secretary of Defense for Acquisition, Technology & Logistics, "DoD Ammunition and Explosives Safety Standards 6055.9-STD," October 5, 2004, 26–27.

[31] Ibid.

[32] Ibid., 42.

obviously achievable in the developed world, the resources required to provide this capability at the village level throughout the undeveloped and developing world are not available.

4. Why Must The Function Be Accomplished?

ERW is a global problem currently without a realistic near-term management solution. The ERW management gap is allowing ERW to remain a threat and hindrance to global development. The ERW-CP will function to eliminate or drastically reduce civilian casualties from ERW awaiting disposal.

5. When Must The Function Be Accomplished?

To address the identified management challenge associated with ERW storage, the ERW management gap needs to be met between discovery and proper disposal. Despite tremendous global efforts, ERW remains a constant daily threat to life and limb. As no silver bullet solution exists to the ERW problem, any solution that can immediately mitigate the negative effects of ERW and is readily availably at the local level is, by definition, appropriate technology and should be implemented.

6. Where and for How Long Must the Function Be Accomplished?

The system or structure must be available at the village or lowest level where ERW affects the population. The intent of the system or structure is not to provide long-term storage of ERW. The intent is to provide expedient short-term storage of ERW awaiting proper disposal. However, the capacity for long-term storage of ERW is required in the event disposal operations are delayed.

As national and international ERW disposal efforts expand to reach previously isolated populations; the ERW solution will facilitate the recording, collation and disposal operation prioritization.

7. How Many Times Must These Functions be Accomplished?

The number of structures required is based on the scope of the ERW contamination problem in the local area. Also associated is proper disposal operation frequency, or lack thereof. The greater the level of ERW contamination, combined with disposal operation scarcity, will require more structures.

Unfortunately, due to inaccuracies and incomplete data, no solid numbers relating to the frequency of discovery to the period of storage for ERW exist. However, "The data available on the casualties of ERW and percentage of UXO cleared again shows a greater bias toward the two main groups—anti-personnel mines and cluster bomblets (submunitions)."[33] Fortunately, these types of munitions fall directly within the design requirements associated with explosive weight and size.

In the event of an unintended ERW detonation, the system or structure is expected to receive catastrophic damage and will be considered no longer usable. As such, the structure's design and construction methodology parameters must allow for replacement structures to be quickly constructed using locally sourced building materials at little to no cost to the local population.

[33] The Geneva International Centre for Humanitarian Demining, "Explosive Remnants of War (ERW), "A Threat Analysis," 2002, 17.

IV. COMPARISON OF ALTERNATIVES

A. DESIGN APPROACHES

1. Commercially Available Solutions

A broad spectrum of existing ERW storage solutions is available. As these solutions are examined, they are evaluated along the following spectrum. At the high end of the spectrum reside large-scale, high cost solutions that provide 100 percent security and protection from any explosive-related accident. At the opposite end of the spectrum reside the lower cost, smaller scale solutions designed to simply mitigate the effects of ammunition and explosive incidents.

2. Large Capacity Structures

a. Performance/Effectiveness

It is not really necessary to go into detail describing the performance and effectiveness of large-scale, purpose built, reinforced concrete ammunition and explosive storage facilities. DoD publication 6055.9-STD Ammunition and Explosive Storage Safety Standards establishes uniform safety standards applicable to ammunition and explosives storage in the developed world. These standards are designed to provide maximum protection to personnel and property exposed to the damaging effects of ammunition and explosives accidents during development, manufacturing, testing, transportation, handling, storage, maintenance, demilitarization, and disposal. The recommended structures range from relatively small, above ground, stand-alone structures designed to hold under 100 lbs. of ordnance to earth covered, multi-unit complexes housing hundreds of thousands of pounds of ordnance.[34]

[34] Department of Defense, Under Secretary of Defense for Acquisition, Technology & Logistics, “DoD Ammunition and Explosives Safety Standards 6055.9-STD.”

Figure 1. Earth-covered magazines

b. Logistics/Maintenance

The robust nature of the facilities required to meet the DoD standards obviously require tremendous resources to design, test and build. Additionally, these facilities require significant levels of backside support to ensure performance levels are maintained over the course of their service life.

At $50,000 for a small 24’ X 10’ X 8’ pre-fabricated earth covered magazine, the cost is significant. Thus, large built-onsite magazines run into the millions

of dollars.[35] Unfortunately, not enough of these types of adequately maintained facilities exist even in the more developed nations of South America, former Easter-Bloc, Asian, and African countries.

The lack of facilities often leads to existing structures being overstocked with incompatible explosive items. These circumstances, in turn, lead to catastrophic incidents. Unfortunately, the data relating undesired explosive events or incidents to improper storage and management is limited. As stated, over half these incidents were not reported, or did not have an accurate report done for the types of ordnance or the NEW of the incident. The 23 incidents that did submit a report estimated the NEW at over 33,203 tons.[36]

Even on the smallest scales and with construction assistance from the developed world, the facilities still need to be managed properly by qualified personnel. Furthermore, the sheer number of facilities required to address the scale of the ERW management problem effectively in the undeveloped and developing world makes first world, large capacity storage facilities an unrealistic option.

3. Containment Devices and Structures

a. Advanced EOD Storage Magazine (EODMAG), ARMAG Corporation

(1) Performance/Effectiveness. The EODMAG is one example of many portable explosive magazines designed to meet the needs of small forward deployed military units and specific law enforcement situations. The EODMAG was design and developed by Naval Air Warfare Center (NAWS) Weapons Division, China Lake for EOD forces. The design was intended to fill a need for a deployable explosives storage magazine with a minimal Explosive Safety Quantity-Distance (ESQD). The system is a steel box of varying sizes from 42” X 42” X 36” to 7’ X 7’ X 7’. The design uses a modified off-the-shelf ARMAG Corporation magazine to provide additional

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[35] U.S. General Services Administration, “GSA Advantage,” May 1, 2012, https://www.gsaadvantage.gov/advantage/catalog/product_detail.do?gsin=11000010647450.

[36] The Geneva International Centre for Humanitarian Demining, ed. Jack Glattbach, “Explosive Remnants of War (ERW)–Undesired Explosive Events in Ammunition Storage Areas,” 36–37.

venting and 17 individual pumice-lined containers designed to prevent sympathetic detonation and limit the maximum credible event (MCE) in the magazine to 1.25 pounds NEW of C-4. The maximum NEW permitted in the magazine is 128.24 pounds. NAWS China Lake Test Report NAWCWD TM 8331[37] defines all conditions and modifications associated with use of the Advanced EOD Magazine.[38]

Figure 2. EODMAG

(2) Logistics/Maintenance. Aside from regular exterior care, such as painting to prevent rust, little to no maintenance is required. A 10-foot area clear of debris and vegetation is required around the EODMAG to meet DoD standards. However, the initial price of the unit and transportation requirements drives deployment costs for this solution over $10,000 U.S. each. Additionally, in the event of an unintended

[37] NAWS China Lake Testing Facility, "NAWS China Lake Test Report TM 8331, DDESB TP 15, VER 2.0," U.S. Navy, 2004.

[38] ARMAG Corp., "Explosive Ordnance Disposal Magazines," May 9, 2011, http://www.armagcorp.com/explosives-magazines/eod.

explosion, the special pumice-lined containers within the unit would require replacement as a reoccurring cost.[39] These factors render the various configurations of the EODMAG too expensive to deploy as a locally viable solution.

b. "Bomb Container," Beijing Yingruida Technology Development Co.

(1) Performance/Effectiveness. The readily available information about Yingruida Technology Development Co. Products is limited. The specifications for the "Bomb Container" are as follows, "Be designed to store the explosives. Widely used in subway station, exhibition center, airport and railway stations. weight: 968kg diameter: 1000 caliber: 700 anti-bombing capacity: 3kg TNT equivalent."[40]

Figure 3. Bomb container

[39] Paul J. Mahoney, "Cost Comparative Analysis of Blast Mitigation Technologies with Regard to Explosive Remnants of War (ERW)," (MBA Project, Naval Postgraduate School, 2011), 17.

[40] Beijing Yingruida Technology Development Co., Ltd., "Explosive Ordnance Disposal," May 9, 2012, http://safetyprotection.en.alibaba.com/productgrouplist-209721204/Explosive_Ordnance_Disposal.html#products.

(2) Logistics/Maintenance. No maintenance requirements are listed; however, basic exterior maintenance can be assumed. It also appears to be a one-time use system, at an advertised price of $30,000 to $35,000 U.S. With no official technical specifications, the concept seems sound but unproven and outrageously expensive. However, they have been widely deployed throughout China's subway systems.

c. JAYCOR Small Blast Containment Device

(1) Performance/Effectiveness. The Jaycore blast containment device is not currently available. However, the design is unique and stands in contrast to the steel containment systems. The Jaycor container dimensions are 2ft x 2ft x 2ft, and it weighs about 55 lbs. It can be transported in the back of a vehicle, and easily carried by one or two people. The system is designed to contain the blast and fragmentation of a pipe bomb containing at least 1 lb. of black or smokeless powder. By comparison, it is the equivalent to a small mortar containing less than half of a pound of plastic explosive.[41] If increased protection against fragmentation is required, additional panels of varying degrees of thickness can be inserted. The Jaycor design is based on the lightweight, blast-resistant cargo container Jaycor has developed for the Federal Aviation Administration to contain the force of the blast and fragments from a bomb placed in checked luggage.

To achieve the desired structural integrity to weight ratio, the Jaycor container design utilizes man-made fibers found in ballistic armor. Although not specifically mentioned, it can be assumed that the material is Kevlar or a similar material. Unfortunately, this design has limitations regarding the opening. Putting an ordinary opening on a container, such as the Jaycor device, negates most of the strengths inherent in the design. To overcome this deficiency, Jaycor developed an opening design that

[41] National Counterterrorism Center, "TNT Equivalents for Various Explosives and Fuel-Air Mixtures," May 1, 2012, http://www.nctc.gov/site/technical/tnt.html.

allows the container to be built with nearly the optimum blast resistant capacity allowed by the material, while maintaining a fully functioning opening.[42]

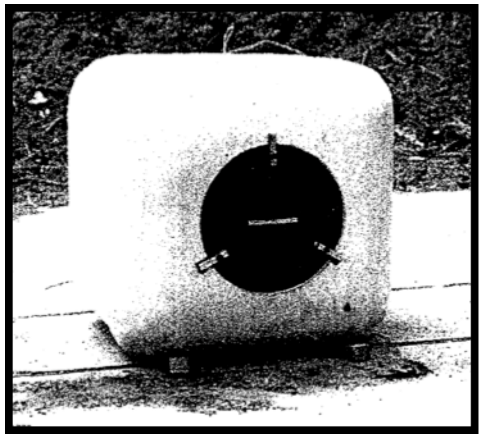

Figure 4. Jaycor small blast containment device

(2) Logistics/Maintenance. As this system is currently unavailable, no logistical requirements are available. Due to the nature of the design, specifically, the use of man made high strength fibers, it can be assumed the cost of this onetime use device is considerable. Additionally, the design parameters of a highly portable device also make it susceptible to theft. However, the use of fiber-based materials to construct and reinforce the structure presents a valuable design option.

4. Mitigation Vessels

Mitigation devices are intended to stop horizontal fragmentation and redirect or mitigate the blast and thermal effects of an explosive detonation. The design and intent of mitigation vessels begins realistically to address the requirements needed to address the ERW management gap. Testing mitigation vessels is quite different than containment devices and structures.

Mitigation is an open-ended term specifically used to describe the effectiveness of a variety of vessel designs in a variety of situations and environments. Just as

[42] H. H. Klein and M. J. Vander Vorst, "Containment Devices for Small Terrorist Bombs for Law Enforcement, Final," *National Institute for Justice, Office of Comptroller*, 1999.

containment device effectiveness and capacity fall along a spectrum, so it is for mitigation vessels. The following section explores mitigation techniques from design specific vessels to supplementary mitigation products.

a. Vorsphere

(1) Performance/Effectiveness. Although advertised as a containment structure, the Vorsphere does not contain the blast; it simply redirects the effects upward, which places it in the mitigation category. The primary objective of the Vorsphere is to provide a re-usable explosive device mitigation system, in varying sizes, that does not need to be secured to the ground or a transport unit. Additionally, variations of the Vorsphere are designed and intended to be cost effective as a disposable unit or a reusable device.

The Vorsphere manufacturing design is metal or a composite material dependent on requirements. The design requirements also expressed the Vorsphere be easy to manufacture, repaired in the field if necessary, and require minimal skill to transport and operate. The dimensions range from a 28” X 27” steel semi-sphere rated up to 1.4-2kg, 3-4.4 lbs. of C4, to a 60” X 59” steel semi-sphere rated up to 6-8kg 13.2-17.6 lbs. of C4.

Figure 5. Vorsphere mitigation device

(2) Logistics/Maintenance. Individual unit prices range from the disposable version at 75 lbs. and a cost of roughly $871 U.S. to 533 lbs. at a cost of roughly $14,367 U.S. Initially, aside from the cost, the design parameters seem promising. The Vorspher's capacity to mitigate and explosion is very impressive. While the size and weight of the larger units limit the probability of theft, the smaller devices are still susceptible. Also, none of the systems provide a way to secure items inside the device. The absence of a lid also leaves any items placed in the vessel exposed to the elements. The design demonstrates a purely detonation mitigation requirement not a storage requirement.

According to the manufacture, no maintenance requirements, other than the assumed removal of water from the collection bin after it rains, are necessary.

b. Bomb Resistant Trash Cans

(1) Bomb Resistant Waste Receptacles, American Innovations, Inc.

- Performance/Effectiveness. The bomb resistant waste receptacle is designed for deployment in urban areas as an explosive mitigation tool. Its triple wall construction is designed and tested to withstand various net explosive weights placed in multiple locations within the receptacle. The design parameters are as follows: containing all horizontal fragmentation from devices placed bottom center, sidewall weld seam, sidewall opposite weld seam, and midpoint. The exterior materials, galvanized edges, walls and drains provide corrosion resistance in most environments. The device is 29" in diameter and 37.5" high. It requires leveling, and anchoring with a single point stainless steel anchor resistant to over 4,000 pounds of shear or tension force.

The following is directly from the manufactures website.

> In order to create a real life deployment scenario, all receptacles must be anchored to a 1" steel slab that is anchored to 6" concrete slab that is anchored to another 1" steel slab. Testing should be conducted with C4 explosives, packed to a specific density in order to ensure an accurate TNT rating was obtained.
>
> Since we can not control where within a trash receptacle an explosive device will be placed, the following tests: bottom center, side wall weld seam, side wall opposite weld seam, and midpoint center detonations are all required for determining an accurate explosive containment rating.

Fragmentation tests should also be conducted using pipe bombs.

Results for determining a successful test:

Outer wall of receptacle did not breach (split, open, or crack).

All horizontal fragmentation contained within the receptacle.

Top to the receptacle did not fragment and detach during explosion.

Figure 6. Bomb resistant waste receptacles

- Logistics/Maintenance. The logistics requirements of a seemingly simple system are surprisingly demanding. Weighing in at 1,400 lbs., this system requires custom designed lifting tools. Although the tools are provided with every order, moving and installing these receptacles requires heavy lifting equipment. The base cost is $2,297.10 each. However, when transportation and instillation is factored in, the cost per unit increases significantly. Additionally, in the event of a detonation, the structural integrity is compromised and the unit must be replaced. According to the website, minimal maintenance is required. However, the design is intended for an urban environment to be used as a trash can. As pointed out with previous blast mitigation systems, there is no lid, which significantly limits the design, and does not allow for storage or the securing of items.[43]

[43] American Innovations, Inc., "Bomb Resistant Waste Receptacles," May 10, 2012, http://www.bombreceptacles.com.

(2) BlastGard MTR, Models 91 and 101, BlastGard International.

- Performance/Effectiveness. A very similar product to the AI waste receptacle is the more robust BlastGards MTR 91,101,300. While the previous product deals with horizontal fragmentation, it does not address the blast and thermal effects. BlastGard has implemented two unique design features to address the blast and thermal effects of an explosive detonation, a lid and use of Perlite. Perlite is a volcanic glass in gradual form that effectively absorbs blast, and extinguishes thermal effects. Testing on the BlastGard series was conducted in the same manner as other mitigation vessels, however, "Due to the sensitive nature of this technology, BlastGard International will not publicize explosives containment ratings of our MTR models."[44] The lid, like traditional trashcan's lids, provides the contents limited protection from the elements, and if lockable, limited security.

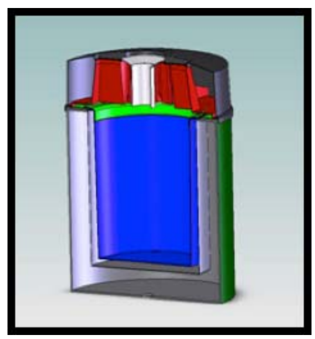

Figure 7. BlastGard 91, 101, 300

- Logistics/Maintenance. Again, the logistical and maintenance requirements are extremely demanding and expensive. Weighing in at approximately 2,500 lbs., many of the same transportation hurdles exist. Although lifting hardware is provided, heavy lifting equipment is still required. The base price for a single unit starts at $4,602.00 U.S. It is unclear if, in the event of a large detonation, the structural integrity is compromised and the entire unit must be replaced. Additional maintenance expenses and logistical requirements are replacement parts. The replacement BlastGard MTR cover, inside top protective shield, side and bottom BlastWrap inserts are $1,500 U.S. per set, and replacement plastic liners are $80 U.S. each.

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44 Blastgard International Inc., "Blastgard International Inc. Products," May 10, 2008, http://www.blastgardintl.com/bp_mtr.html.

c. Bomb Basket

(1) Performance/Effectiveness. The Bomb Basket is a generic name for several variations of the same device originating in India. The Bomb Basket's design is very rudimentary. Its tube enclosure is manufactured from ballistic fiberglass woven composite with a gel coat finish. The manufacturer claims that the Bomb Basket can mitigate the effects of, and contain the fragments from a 200 grams (or .44 lbs.) RDX-[45]based explosive device. The vented removable inner bag is made of a fire retardant nylon net and keeps the item centered in the vessel as best as possible.

Figure 8. Blast basket

(2) Logistics/Maintenance. At 36" X 24" X 1¼" thick and 110 lbs., the logistical requirements are significantly less than the previous mitigation techniques. The one time use unit cost is unknown. However, as noted, at .44 lbs., it has limited mitigation capability and applications. On an additional note, no "official" test results exist, which renders any and all claims unsubstantiated . [46]

d. Blast Wrap, Blastgard International

(1) Performance/Effectiveness. BlastWrap is a blast mitigation product designed to be wrapped around or conform to any shape. BlastWrap is made

[45] RDX is an explosive compound similar to C-4.

[46] Magnaera, "Bomb Basket," May 10, 2010, http://www.magnaera.com/bomb_basket.htm.

from two laminated films formed into pockets containing blast reducing filler materials including volcanic glass bead (vermiculite) or other materials, and a blend of extinguishants designed to mitigate all blast and thermal effects of an explosion. BlastWrap works by mitigating blast wave energy by rapidly extinguishing the thermal output of an explosion, integrated into one of two basic categories, barriers or containers. BlastWrap is a passive blast and thermal mitigation technique that can be used in confined and unconfined spaces, but is obviously, not a fragmentation mitigation product. It can essentially be applied to any structure or device deemed a fragmentation mitigation product.

Figure 9. BlastWrap

(2) Logistics/Maintenance. The logistic and maintenance requirements are minimal for this product. It can be shipped anywhere in the world with relative ease. However, it is a one-time use product and will need to be replaced in the event of an unplanned detonation. Cost will depend on the level of mitigation required and the number of mitigation vessels required in relation to ERW contamination levels. Based on these variables, and the initial price of $71.25 US per sq. ft., the initial cost and subsequent replacement costs become significant. A small four-foot by four-foot box completely lined with Blastwrap would cost $6840.00 U.S., not including the materials used to construct the box.

5. Improvised Mitigation Techniques and Solutions

Improvised solutions realistically address the requirements needed to bridge the ERW management gap. Testing improvised mitigation solutions, if at all possible, is quite different than containment devices or commercially available mitigation vessels. Improvised mitigation devices are intended to stop horizontal fragmentation and or lessen the blast and thermal effects of an explosive detonation. Just as containment devices and mitigation vessel, effectiveness and capacity fall along a spectrum; improvised mitigation techniques and solutions fall along an even broader spectrum.

a. Sandbag Bunker and Earth Berms

(1) Performance/Effectiveness. Sandbag mitigation techniques are widely used to minimize fragmentation, blast, and thermal effects of an explosion, and are often used by EOD personnel to dispose of an ordnance item in place. Additionally, they can be modified to provide temporary storage of ERW. According to EOD manuals, the following technique is limited to munitions up to 155mm (6") in diameter, which typically contain approximately 15 lbs. of high explosive.

The preferred construction material is fabric woven, polypropylene sandbags filled with clean dry sand, as wet sand may produce voids within the sandbag. Shown in Figure 10, four walls of identical thickness are constructed around the munition or device. The thickness of the wall is determined by the diameter and assumed NEW of the item. An air gap of 6 inches between the munition and the inside face of each wall and ceiling should be maintained. The interior face of each wall must be vertical and the outside must have a 1:6 slope.[47]

[47] Naval Explosive Ordnance Disposal Technology Division, "Protection of Personnel and Property," U.S. Navy, Indian Head, MD, 2012, 47.

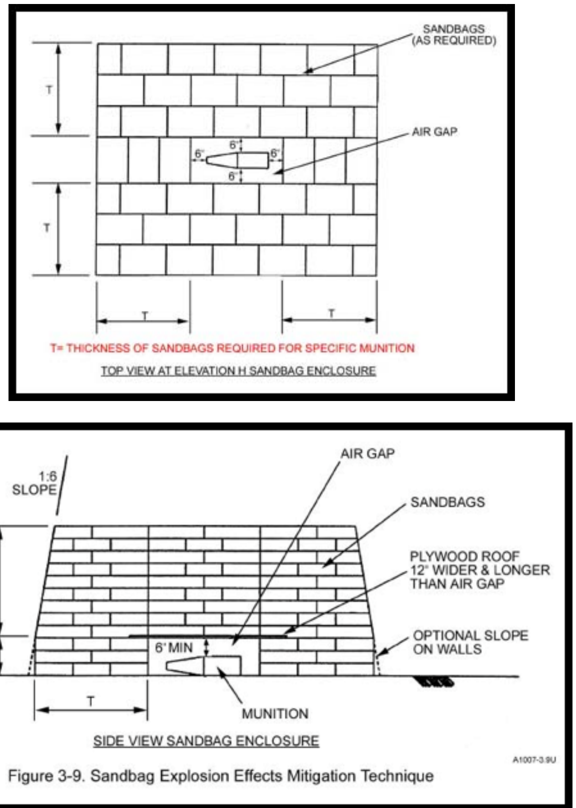

Figure 10. Sandbag mitigation technique

(1) Logistics/Maintenance. This technique is simple, and it is quite effective. However, logistical hurdles need to be overcome. Although scalable, it requires a significant footprint for a single item, and acquiring a sufficient amount of sandbags and sand in remote locations may become an issue. In the spirit of improvisation, woven rice or grain bags and local sandy soil could be used as a substitute. The required modifications needed to store ERW within the structure are minimal. However, with the addition of an opening, the ability to mitigate the effects of an explosion is greatly reduced. To compensate, an additional sandbag structure just outside the door is required. Additionally, this modified technique leaves the ERW exposed to the elements and theft.

Earth berms are in essence a continuous, circular dirt pile surrounding the item working in the same way as a sandbag bunker minus the top or roof. Earth berms require an even larger footprint and usually require a larger work force or

heavy equipment to facilitate construction. Since they are not an enclosed structure, it is not possible to provide sufficient protection from the elements or secure items from theft.

b. Tires

(1) Performance/Effectiveness. Tires have been used extensively throughout the undeveloped and developing- world to mitigate blast effects, from basic stacks of car tires to large truck tires modified into “Bomb Baskets.” The inherent properties of a modern tire make a logical protective material; steel belted reinforced rubber with a cylindrical shape. Unfortunately, explosive reactions take the path of least resistance[48] and will escape through any gap, or expand into any crack or crevice of which a stack of tires has many. However, something is better than nothing.

Theoretically, based on surface area and thickness, the larger the tires are, the more protection they will provide from horizontal fragmentation. Wider tires will stack higher with fewer tiers, and as such, eliminates gaps. Additionally, the more space an explosive reaction has to expand, the less powerful it becomes. Semi-truck tires and heavy equipment tires usually have 20” or greater rim diameters and even larger interior spaces allowing for greater expansion.

(2) Logistics/Maintenance. No logistical “requirements” exist because this approach uses readily available materials. This technique, while not reliable or necessarily effective, is a perfect example of doing what you can, with what you have, where you are, when you have to. It falls directly into the design parameters and requirements of dealing with the global ERW problem on the appropriate level and scale. Figure 11 is an example from the Philippines of a single large tire mitigation technique. Although ingenuitive, it does not provide an ERW-management solution.

[48] *Blasters Handbook*, 18th ed. (Cleveland, OH: International Society of Explosives Engineers, 2011), 341.

Figure 11. Improvised "Bomb Basket" in Southern Luzon, Philippines

B. PREFERRED APPROACH

1. Hybrid Approach

The hybrid approach can be described as a state of the art design concept that utilizes undeveloped/developing-world construction materials and methodology. Using this method, performance and effectiveness criteria are limited to the material used, not the design.

Since man transitioned from nomadic tribes to sedentary farming, numerous building materials and construction techniques have developed throughout the world, that utilize the most appropriate materials available in the region. By referencing existing studies and running robust materials testing simulations on a myriad of locally used building materials and techniques, a suitable design or series of designs can be developed and implemented. The intent is to use local building materials; therefore, the design will need to make limited to nonexistent logistics and maintenance requirements a main priority. In other words, it needs to simple and hassle free.

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V. IMPLEMENTATION

A. DISTRIBUTION AND DEPLOYMENT

1. Global Problem, Global Requirements

The ERW problem is a global problem, and will require globally deployable solutions. As this makes it desirable for the design concept proposed, as a solution, it must be presented in a universally exportable format. This concept can be accomplished digitally via the Internet, which now reaches even into the most undeveloped parts of the world, as well as good old fashion hard copy paper and ink, and person-to-person exchanges via the numerous international initiatives to combat the ERW problem.

B. MISSION PROFILES AND SCENARIOS: KNOWLEDGE DELIVERY PLATFORMS

1. International Aid

As discussed in the introduction, efforts across the spectrum of International Aid attempt to address the ERW problem. From robust national Mine/UXO awareness programs, to multilateral military programs, to the most benign aid organizations, they all face the same problems. The "Don't touch it, mark it, report it"[49] mantra, while targeting the lowest common denominator, is idealistic and unrealistic if no reliable reporting and or disposal capacity exists.

Any of these efforts would benefit from the development of universal, cost effective ERW mitigation and management solutions. However, money and technology alone cannot fix the ERW problem. The age-old adage of teaching an individual to fish rather than giving them a fish must be implemented, which must be accomplished through the implementation of appropriate solutions at the appropriate levels. Proposed solutions must be transferable to the lowest levels of interaction, and subsequent levels of assistance/aid, while adhering to the global Mine/UXO awareness programs.

[49] United Nations, "International Guidelines for Landmine and Unexploded Ordnance Awareness Education."

2. U.S. Military Efforts

a. U.S. DoD Humanitarian Demining Program (HD)

U.S. forces deployed to host nations cannot actively conduct demining operations, e.g., searching for and digging mines out of the ground. However working, by, with, and through partner nations, demining aid in all other forms may be provided. One such avenue is through research and development. The HD R&D Program focuses on developing and testing demining tactics, techniques and procedures that increase the safety and efficiency of demining operations. HD R&D adapts commercial-off-the-shelf technologies (COTS), uses mature technologies, or leverages existing military technologies to meet the challenges that face landmine affected populations and deminers in mine and minefield detection, area reduction, vegetation clearance, mechanical mine clearance and mine neutralization. Currently, their focus is not specifically on ERW storage. However, ERW mitigation does fall under their purview.[50]

The Office of the Assistant Secretary of Defense, Special Operations & Low Intensity Conflict (OASD SO/LIC) provides policy guidance and oversight for HD. OASD SO/LIC reviews and approves requests for in-country field assessments and operational field evaluations, and is also responsible for communicating with the U.S. Department of State's humanitarian demining efforts.[51] Under this structure, the ERW-CP concept could be widely shared and field evaluations could begin immediately.

b. Foreign Internal Defense (FID)

Once approved, the ERW-CP concept can be implemented through U.S. FID efforts via Humanitarian and Civic Assistance (HCA) programs. The U.S. FID mission is to support a host nation's internal defense and development via a full range of actions and programs. Of these programs, the HCA, allows for the development of medical facilities, the drilling of wells, transportation projects and programs, basic

[50] Once a landmine is discovered, recovered and rendered safe, it becomes an explosive remnant of war, and is no longer classified as an active landmine.

[51] U.S. Department of Defense Humanitarian Demining R&D Program, "Research and Development Program Overview," May 31, 2012, http://www.humanitarian-demining.org/2010Design/Program_Overview.asp.

construction and repairs to public facilities, and of course, the development of facilities and programs used in providing education concerning the detection and clearing of landmines and other explosive remnants of war.[52] The nature of the ERW-CP concept falls directly into the framework and intent of the FID/HCA mission.

c. Village Stability Operations (VSO)

VSO are conducted primarily in Afghanistan and are intended to protect rural and remote populations, prevent intimidation and exploitation by insurgent forces, and increase security and stability in an area. Ultimately, VSO's goal is to expand the influence of the Afghan government. Through implementation of bottom-up village and district defense systems, VSO complement top-down national-level Afghan National Security Forces (ANSF) development. "The goal of VSO is to empower and galvanize Afghans to stand up for themselves against insurgents and to generate Afghan solutions for Afghan problems."[53]

The VSO methodology is comprised of four phases: shape, hold, build, and expand/transition. Fundamentally, VSO is designed to take a conditions-based approach, scalable to the dynamic conditions faced in the various areas of responsibility and situations of stability operations. Unlike FID, U.S. personnel supporting VSO are embedded at the village level and are actively engaged in combat operations.

During the second, or hold phase of VSO, emphasis is placed on protecting the population. The hold phase begins once the team has successfully embedded in the village and begins to develop a "stability bubble" around it. During this phase, Special Operations Forces train a contingent of Afghan Local Police (ALP) comprised of the local villagers. If an immediate security threat does not exist, a situation may occur in operations will focus on development while simultaneously bolstering

[52] U.S. Department of Defense, DTIC, "Joint Publication 3-22 Foreign Internal Defense Operations," July 12, 2010, VI–23.

[53] Headquarters Combined Joint Special Operations Task Force–Afghanistan, Bagram Airbase, "Village Stability Operations and Afghan Local Police: Bottom-up Counterinsurgency," 2011, 8.

levels of security.[54] These operations often entail dealing with armed deployed landmines, deployed and abandon IEDs, UXO, and SA/LW weapons caches.[55] Unfortunately, due to the isolated areas in which VSO is often conducted, EOD forces are not always immediately available to dispose of these hazards, which forces U.S. and local personnel to find an alternative solution to the secure ERW storage problem. Based on these conditions, VSO provides a near perfect platform for the implementation of the ERW-CP concept.

3. Aid Organizations

The range and levels of NGOs and Intentional Aid Organizations (IAO) actively working to address the landmine and ERW global problem is astounding. The very nature of free flowing information inherent within the IAO allows for maximum proliferation of the ERW-CP concept. Often hindered by access to funding and logistical support, the design requirements of the ERW-CP were developed with all levels of aid in mind.

4. Local Efforts

As presented in Chapter II, village demining activities are becoming more frequent. Local populations lacking in formal training and access to the proper demining equipment are executing demining by necessity. As dissemination of the ERW-CP construction methodology does not require a national program, these local efforts would probably benefit the most from the ERW-CP concept.

C. PERFORMANCE PARAMETERS

1. Safety Requirements

To be legitimately accepted by the international community as an explosive mitigation device, at a minimum, the structure must stop the lethal affects of ERW-produced fragmentation without creating any secondary fragmentation from the structure

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[54] Headquarters Combined Joint Special Operations Task Force–Afghanistan, Bagram Airbase, "Village Stability Operations and Afghan Local Police: Bottom-up Counterinsurgency."

[55] With the exception of armed actively deployed landmines and IEDs, abandoned IEDs, UXO, and SA/LW weapons caches are all considered ERW.

itself or the surrounding area, which must be accomplished while redirecting the thermal effects and blast overpressure wave away from the population. The easiest way to provide protection from the effects of thermal and blast waves is distance. The greater the distance from the explosion, the less the negative effect, but to lessen the footprint required to provide an acceptable level of protection, the distance between collection points and populated areas needs to be minimal. The structure should provide protection from blast wave effects as close as possible to a K-Factor of 24. A K-Factor of 24 or K-24 (31 ft. or 9 m) is the minimum distance an individual can be from a non-fragmentation producing an l lb. TNT equivalent explosive detonation without receiving life threatening injuries. As depicted in Figure 12, the lowest recommended distance for a one pound explosion is K-50 (15 meters or 50 ft.); however, this chart assumes that a single authority has complete control of the 50-ft. area and situation at all times. This distance is the absolute minimum emergency responders, such as trained EOD technicians, are allowed to remain and observe. It is assumed that in an uncontrolled environment, smaller protective distances are suggested.[56]

[56] Naval Explosive Ordnance Disposal Technology Division, "Protection of Personnel and Property," Indian Head, MD, 2012.

Table 3-4. HFDR and MFDR Determined by the Net Explosive Weight of a Single Item (Sheet 1 of 4).					
NEWQD Pounds (Kilograms)		Hazardous Fragmentation Distance Range (HFDR) Feet (Meters)	Maximum Fragmentation Distance Range (MFDR) Feet (Meters)	Blast Overpressure Distance Range (BODR) Feet (Meters)	
		[1] $315.9 \times W^{0.164}$	[1] $2756 + 565.9 \times \ln(W)$	K328	K50
>	≤	[2] $(109.62 \times Q^{0.164})$	[2] $(976.4 + 172.5 \times \ln(Q))$	K(m)130.1	(K(m)19.84)
0.0	0.10	217	1,453	152	23
(0.0)	(0.05)	(66)	(443)	(46)	(7)
0.10	0.20	243	1,845	192	29
(0.05)	(0.09)	(74)	(562)	(59)	(9)
0.20	0.30	266	2,075	220	33
(0.09)	(0.14)	(81)	(632)	(67)	(10)
0.30	0.40	272	2,237	242	37
(0.14)	(0.18)	(83)	(682)	(74)	(11)
0.40	0.50	282	2,364	260	40
(0.18)	(0.23)	(86)	(721)	(79)	(12)
0.50	0.60	291	2,467	277	42
(0.23)	(0.27)	(89)	(752)	(84)	(13)
0.60	0.70	298	2,554	291	44
(0.27)	(0.32)	(91)	(778)	(88.6)	(13)
0.70	0.80	305	2,630	304	46
(0.32)	(0.36)	(93)	(802)	(93)	(14)
0.80	0.90	310	2,696	317	48
(0.36)	(0.41)	(94)	(821)	(97)	(15)
0.90	1.0	316	2,756	328	50
(0.41)	(0.45)	(96)	(1,250)	(100)	(15)
1.0	2.0	354	3,148	413	63
(0.45)	(0.91)	(109)	(960)	(126)	(19)
2.0	3.0	378	3,378	473	72
(0.91)	(1.4)	(115)	(1,030)	(144)	(22)
3.0	4.0	397	3,540	521	79
(1.36)	(1.8)	(121)	(1,079)	(159)	(24)
4.0	5.0	411	3,667	561	85
(1.8)	(2.3)	(125)	(1,118)	(171)	(26)

NEWQD Net Explosive Weight Pounds	HFDR Hazardous Frag Distance Range Feet/meters	MFDR Maximum Frag Distance Range Feet/meters	BODR K-50 Blast Overpressure Distance Range Feet/meters
1	316/96	2756/1250	50/15

Figure 12. Excerpt from K-Factor chart

Much like the limits of the sandbag mitigation technique, any ordnance item over 6" in diameter will likely contain much more than 1 lb. of explosive. This being the case, only the most robust containment facilities will provide the required levels of protection and are outside the design parameters of this effort. However, distance is the best and

cheapest mitigation technique. For larger ordnance, such as 155mm projectiles and large anti-tank landmines, the structure can be placed at a much greater distance from the population and still act as an effective secure collection point.

D. UTILIZATION REQUIREMENTS

1. Access and Security

The design concept is based at the lowest levels of expertise, and assumes that no training concerning ERW, explosives, or proper ordnance handling exists. Therefore, the structure must be clearly marked and easily accessible to untrained personnel, while providing secure storage for ERW. Due to lack of training, structures will be limited to 2 lbs. NEW, or roughly two to three small items or maximum, one, six" diameter item to alleviate explosive compatibility issues and the tendency to stockpile ERW items. No doubt multiple structures in areas with high ERW concentrations will be required. Also, the ability to secure items will protect them from theft, tampering, as well as further deterioration from the elements.

2. Adhering to International Guidelines for Landmine and Unexploded Ordnance Awareness Education

To implement an ERW management and mitigation system properly, certain issues must be addressed. First, adherence to the UN's "International Guidelines for Landmine and Unexploded Ordnance Awareness Education"[57] programs must be maintained. Second, a simple, universally acceptable, procedure must be disseminated and implemented to get the ERW from the discovery site to be secured in the structure.

First, the UN Mine/UXO awareness mantra "Don't touch it, mark it, report it"[58] while idealistic, should be followed, which may seem contradictory to the concept of a locally managed ERW storage structure. However, an ERW structure is only needed when no reliable reporting system above the local authority exists or, even when reported, the capacity to dispose of the ERW in a timely manner is not available. To

[57] United Nations, " International Guidelines for Landmine and Unexploded Ordnance Awareness Education."

[58] Ibid.

adhere to the global Mine/UXO awareness programs, the ERW mitigation effort must hinge on following Mine/UXO awareness reporting procedures at the lowest levels of authority.

Second, in accordance with Mine/UXO awareness efforts, after the ERW is discovered and marked, the discovering individual must report the incident to the local leader or whoever the local reporting authority is. It then falls upon that local leader to determine an acceptable course of action. If a reporting system above the local level has been established but is unable to respond in what that local leader deems an effective timeframe, the leader has an alternative if aware of the ERW-CP concept. Once it is determined by the empowered local leader that action must be taken, this individual assumes the risk, and thus, a simple line pull procedure[59] and wait time can be preformed. After a successful line pull procedure, the ERW can then be transported to and secured within the structure.

E. EFFECTIVENESS REQUIREMENTS

1. Cost-Based

Due to the scope of the ERW problem, a universally inexpensive, preferably free, easily constructed and reproducible structure must be designed. Based on these parameters, local building materials and techniques must be used. Local building materials vary as drastically as the global environment; however, salient alternatives are available across the globe. As the building materials become less important, the concept of design becomes the nucleus of effort. The design must be based on proven blast mitigation concepts adapted from materials that exist naturally or are available nearly everywhere. Reinforced concrete and man-made, high-strength fibers are the optimal choice. However, using readily available or naturally occurring materials that reasonably

[59] A “line pull” is a procedure used to remotely move or disturb UXO from a safe distance from under frontal and overhead protection. The procedure consists of evacuating the area surrounding the UXO of personnel. Secondly, without moving it, a line is tied to the UXO. Once the line is around the UXO, the individual backs out to the predetermined safe distance and takes frontal and overhead cover. The individual then forcefully pulls the UXO several feet from its original resting place and waits one hour. If the UXO does not detonate, and is deemed safe to move, it can be transported.

replicate the same properties should be used if these materials are the only ones available. These alternative materials, such as hemp, sugar cane, and coir (coconut husk), are explored in the Technical Performance Measures chapter.

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VI. LOGISTICS AND MAINTENANCE CONCEPT

A. LOGISTICS

Ideally, minimal logistic requirements will be necessary. By adhering to design requirements, the local labor force using locally sourced building materials should be able to implement the design concept in place. In cases in which direct aid is being provided by outside sources, procuring the building materials and hiring a local labor force is desired as opposed to purchasing a COTS mitigation solution or hiring an outside contractor to fabricate one.

B. LEVELS OF MAINTENANCE

1. Materials Based

Maintenance should be negligible on the structure. In concert with design parameters, some form of water proofing, such as paint or a locally derived alternative, will be required. It is recommended that white or bright color paint be used not only as a warning, but to reduce the effects of radiant heat energy caused by ultraviolet rays. Also, the structure must be clearly marked as containing an explosive hazard. These markings will need to be maintained. An example of the international symbols for explosive hazards and mines is provided in Figure 13.

Figure 13. International explosive hazard symbols

C. REPAIR POLICIES

1. Replacement

The requirement is for an easy-to-construct local solution that can be produced as required when structures are expended or capacity exceeded. In the event of an unintended detonation, the structure will assumedly receive catastrophic damage and need to be completely replaced. If capacity is reached, such as one or two items, another structure must be built.

VII. TECHNICAL PERFORMANCE MEASURES

A. BUILDING MATERIAL REINFORCEMENT TECHNIQUES

1. Introduction

The structural properties set forth in the design requirements naturally lean toward a reinforced concrete structure. However, as stated, modern reinforced concrete structures are unrealistic due to material availability, logistical requirements and construction cost. Fortunately, valid substitutes to re-bar and synthetic fiber-reinforced concrete are available.

Cements have been used in building materials for centuries. Using fibers to reinforce building materials is not a new concept either. Chopped straw has been used to reinforce mud bricks throughout their existence, while fibers like horsehair were used to reinforce masonry mortar and plaster. According to the American Concrete Institute (ACI), modern fibers, such as asbestos, were used in cement as far back as 1898, and are still widely used throughout the world today, despite their known health hazards. Patents using fibers to improve the properties of concrete through discontinuous steel reinforcement elements, such as nails, wire segments, and metal chips, date back to the early 1900s.

Alternative fibers to asbestos were introduced throughout the 1960s and 1970s in a variety of building products and production techniques to enhance composite properties. Enhanced properties include tensile strength, compressive strength, elastic modulus, crack resistance, crack control, durability, fatigue life, resistance to impact and abrasion, shrinkage, expansion, thermal characteristics, and fire resistance.

Unfortunately, initial attempts at using natural and synthetic fibers, such as hemp, coir, nylon and polypropylene, were not as successful as glass or steel fibers. However, methods of fabrication and a better understanding of fiber reinforcement have led researchers to believe that synthetic and natural fibers can effectively reinforce building materials.[60]

2. Natural Fiber Reinforced Concrete (NFRC) Building Techniques

Naturally occurring, discontinuous short cellulose fibers are widely used in Fiber Reinforced Concrete (FRC) all over the world. Termed natural fiber reinforced concrete (NFRC), its applications are numerous and include modern synthetically reinforced building materials. A myriad of natural reinforcing materials can be obtained at little cost, or for free, as agricultural byproducts using locally available manpower and technical expertise. Fibers, such as hemp and jute, are often used in the manufacture of low fiber content building materials and are typically referred to as unprocessed natural fibers (UNF).[61] However, as the fiber content is increased, the material strength increases. The concept of using UNFs falls directly into the design requirements. A list of UNF and properties are covered later in this chapter.

3. Synthetic Fiber Reinforced Concrete (SNFRC) Techniques

A variety of fiber materials other than steel, glass, or natural fibers have been developed and used to reinforce building materials, most commonly concrete. These fibers are categorized as synthetic fibers and are used in cement products generally termed SNFRC. Some of these fibers have little reported research while others, such as polypropylene, are often found in commercial applications and have been tested extensively.

Interest in synthetic fibers as a component of building materials was first reported in 1965. Synthetic monofilament fibers were used in blast resistant structures for the U.S. Army Corps of Engineers Research and Development Section. The fibers were roughly

[60] ACI Committee 232, "Use of Raw or Processed Natural Pozzolans in Concrete, ACI 232.1R-00, American Concrete Institute, 2001, 2–3.

[61] Ibid., 57–58.

the same size and shape as the steel fibers, or Steel Fiber Reinforced Concrete (SFRC) and glass fibers, Glass Fiber Reinforced Concrete (GFRC), being tested. The fibers were one-half to one inch in length with a fiber aspect ratio (length to diameter, l/d) of between 50 and 100. This project discovered that with the addition of small quantities, 0.5 percent by volume of synthetic fibers, the concrete composite's ductility and impact resistance increased significantly.[62]

Unfortunately, commercially available synthetic fibers are expensive, and hence, it can be assumed that they are not readily available throughout the world. However, the concept of using synthetic materials to reinforce the design's building materials is still valid. Many synthetic materials can be found throughout the world as waste, such as plastic bags, water bottles, and discarded polypropylene rope that has reached the end of its service life. Theoretically, any of these or other man-made material with acceptable tensile strength could be used as a substitute or addition.

B. FIBER REINFORCED BUILDING MATERIALS

The ACI has a extensive collection of studies conducted on all aspects of cement building materials, from state-of-the-art synthetically reinforced concrete to alternative pozzolans, and natural fibers to soil cement properties. The entire scope of building materials can be applied to the alternatives required in the undeveloped and developing world building solutions set forth in the design requirements.

1. Portland Cement, Pozzolans and Soil Cements

Lime and limestone are among the oldest materials used by mankind for construction purposes, including the pyramids of Egypt. The oldest example of a hydraulic binder dates back to 5,000–4,000 B.C., and was a mixture of lime, a natural pozzolan and diatomaceous earth, roughly 3,000 years before the discovery of Portland cement in 1824.[63]

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62 ACI Committee 544, "State-of-the-Art Report on Fiber Reinforced Concrete: ACI 544.1R-96," American Concrete Institute, 2001, 39–40.

63 ACI Committee 232, "Use of Raw or Processed Natural Pozzolans in Concrete, ACI 232.1R-00, 1.

Currently, Portland cement is the most commonly used and recommended building cements in common construction methodologies throughout the world. Several types of modern, common Portland cements exist: Portland blast furnace cement, Portland fly ash cement, Portland pozzolan cement, Portland silica fume cement and many others. Although Portland cement is readily available throughout the world, in very isolated areas, it may be very scarce or expensive. In the absence of readily available or inexpensive Portland cement, alternative pozzolans can be used to improve the qualities and volume of building materials. The nature of the ERW problem effects all environments, and therefore, all building materials and options should be taken into consideration.[64]

A pozzolan is "...a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties."[65]

A natural Pozzolan is "...either a raw or calcined [heated] natural material that has pozzolanic properties (for example, volcanic ash or pumicite, opaline chert and shales, tuffs, and some diatomaceous earths)."[66] Pozzolans used on an industrial scale, such as fly ash and silica fume, are artificial pozzolans produced from industrial processes. These pozzolans are still a viable option if available. The following is a discussion of some natural pozzolans produced in various parts of the world that would be suitable for use in the design of the structure.

Santorin earth is produced from a natural deposit of volcanic ash of dacitic composition. Pozzolana is a pumice ash comprised of trachyte found in Italy. Trachyte is a volcanic rock comprised primarily of feldspar crystals in a matrix of siliceous glass. The deposit near Pozzuoli is the source of the term "pozzolan" given to all materials having similar properties. Rhenish trass, another pozzolan of volcanic origin, was used

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[64] ACI Committee 117, Standard Tolerances for Concrete Construction and Materials, ACI 117-90, American Concrete Institute, 1990, 2.

[65] ACI Committee 232, "Use of Raw or Processed Natural Pozzolans in Concrete, ACI 232.1R-00, 3.

[66] Ibid.

extensively throughout Roman times. The material is a volcanic ash found in Germany. Gaize is a pozzolan of porous sedimentary rock consisting mainly of opal. The material is usually calcined at high temperatures before used as a pozzolan for Portland pozzolan cement.[67]

Metakaolin is a natural pozzolan produced by heating kaolin-containing clays that forces it to recrystallize, and turns it into mullite or spinel, another amorphous silica. Approximately 250,000 metric tons (227,300 tons) of locally sourced calcined kaolinitic clay was used in the construction of four hydroelectric dams in Brazil at approximately 1/3 the cost of Portland cement.[68]

Rice husk ash (RHA) is a pozzolan produced from burning rice husks, which are a byproduct produced during the agricultural processing of rice. Rice husks are approximately 50% cellulose, 30% lignin, and 20% silica. After the agricultural process, the remaining rice husks are incinerated, which leaves behind an ash consisting mainly of amorphous silica. Chemical analysis of fully burnt RHA shows that the amorphous silica content ranges between 90–96% and produces a highly active pozzolan. These characteristics make RHA suitable for making high-quality cement and concrete products. The benefits of using RHA are higher compressive strengths, decreased moisture permeability, resistance to sulfate attack, resistance to acid attack, reduction of surface cracking, resistance to chloride penetration, and outstanding performance under freezing-and-thawing cycling.[69]

RHA is readily available throughout the undeveloped and developing-world where rice is grown and shows the most promise of filling the building materials design requirements.

Soil cements are another readily available building material that can act as a suitable replacement for primarily cement-based building materials. As defined by the ACI, soil cements are "...a mixture of soil and measured amounts of Portland cement and

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[67] ACI Committee 232, "Use of Raw or Processed Natural Pozzolans in Concrete, ACI 232.1R-00, 4.

[68] Ibid., 6–7.

[69] Ibid., 6.

water compacted to a high density."[70] Soil cement is further defined as a blended, compacted and cured mixture of soil, aggregates/fibers, Portland cement, pozzolans, and water. The Portland cement bonds the soil and aggregates or fibers, but unlike concrete, the individual particles are not completely encapsulated by the Portland cement paste. Essentially, soil cement is a modern version of Adobe. Almost all types of soils can be used for soil cement. Exceptions include highly organic soils, highly plastic clays, and poorly reacting sandy soils. Its use is highly recommended in areas in which clay content in the soil is high, often where adobe construction is historically prominent.[71]

Rammed earth is another name for soil cement used to construct walls. Rammed earth walls, like the ones predominantly found in Afghanistan, can be over two feet thick and can last for centuries. Rammed earth walls can be constructed by placing damp soil cement material into forms to make bricks. Or, more commonly, a wetter soil cement is placed or compacted in four to six inch thick layers or lifts. After setting and curing, the wall can be covered with stucco or simply painted. A typical rammed-earth/soil cement mix consists of 70% sand, 30% soil, and 4 to 15% cement by weight, with the average around 7%.[72] With the addition of fiber reinforcements, the strength, and volume of soil cement building materials will increase significantly.

2. Unprocessed Natural Fibers

Mix proportions for UNF reinforced concrete "...cannot be generalized since there are a variety of natural fibers that can be used in conjunction with the other standard ingredients such as cement, pozzolans, fine aggregates, water, and admixtures."[73] However, two methods of mixing and placing UNF reinforced building materials exist, wet mixing and dry-compacted mixing.

In the wet mix, a low volume of fibers is used. The cement and water slurry is first added to any aggregates then the fiber is added to the slurry until proper consistency

[70] ACI Committee 230, "State-of-the-Art Report on Soil Cement, ACI 230.1R-90," American Concrete Institute, 1997, 2.

[71] Ibid.

[72] Ibid., 6.

[73] Committee 544, "State-of-the-Art Report on Fiber Reinforced Concrete: ACI 544.1R-96," 61.

and workability is reached. In the dry-compacted mix, the amount of fiber used is about 10 times that of the wet mix. The fibers are saturated with water then added to the cement and aggregates to reach the desired consistency. This mixing process can be done by hand.[74]

The following table of naturally occurring fibers suitable for reinforcement is extensive, but not exhaustive. The list is comprised of fibers spanning the globe to demonstrate applicability and availability.

S Bagasse (Sugar Cane Pulp)	Phormium (New Zealand Flax)	Indian hemp (Dogbane)	Papaya
Reed Fiber	Ramie (China grass cloth)	Sisal (Often termed agave)	Coir (fiber from the coconut shell)
Palm Fiber	Bamboo fiber	Umbrella plant	Milkweed
Piña	Abacá	Cotton	Kapok
Bast fibers	Nettles	Esparto	Bowstring Hemp
Jute	Kenaf	Henequen	Hemp
Flax	Hoopvine	Elephant Grass	Yucca (An agave)
Water Reed	Plantain	Musamba	Wood Fiber (kraft pulp)
Maguey	Lechuguilla	Banana Leaf	Guaney

Table 1. Natural fibers

The following section explores a range of tested natural fibers from AIC's Fiber Reinforced Concrete Report 544.1R-59.

Coir, or coconut fibers, comprises the outer shell of the coconut called the husk. The husk has a hard skin and thick layer of fibers embedded in a soft material. Retting, the process used for extracting the fibers, or coir, is widely used in the undeveloped countries of the world. In more developed regions, it is common to use a mechanical

[74] Committee 544, "State-of-the-Art Report on Fiber Reinforced Concrete: ACI 544.1R-96," 60.

process to separate the fibers. Although coconut cultivation is often limited to the tropical regions of Africa, Asia, and Central America, these areas are some of the most widely affected by ERW.

A considerable amount of research has been conducted on the use of sisal fibers to develop quality fiber reinforced concrete products on the industrial level. These fibers are stronger than most of the other natural fibers, as demonstrated in Table 2.

Sugar cane is widely cultivated and used in both tropical and sub-tropical regions. Sugar cane bagasse is the material remaining after the extraction process and contains about 50% fiber and 30% pith with 20% other solids. To obtain suitable fibers, the pith and other solids are removed from the fibers. The properties of bagasse fibers depend on the variety of the sugar cane, and to a large extent, its maturity. However, the process is widely practiced through the region and is often done at the local level. The properties are also outlined in Table 2.

Bamboo grows naturally and quickly in tropical and sub-tropical regions to a height of 50 ft. with diameters varying within the range of 1” to 4”. Dried bamboo stems are commonly used for building temporary structures wherever available. It is also used for continuous reinforcing, or a re-bar substitute, in concrete. Bamboo is also turned into fibers through a simple process often done at the local level.

Flax is grown mainly for its fiber; both tensile strength and the modulus of elasticity are extremely high compared to those of other natural fibers.

Jute is a fiber very similar to hemp and is also grown mainly for its fibers in central and Southeast Asia. Primarily used for making ropes and grain sacks, jute’s strong tension properties make it an excellent choice as fiber reinforcement. The process for extracting jute fibers is simple and end products are readily available throughout the world.

Fiber type	Coconut	Sisal	Sugar cane Bagasse	Bamboo	Jute	Flax	Elephant grass	Water reed	Plantain	Musamba	Wood fiber (kraft pulp)
Fiber length, in.	2-4	N/A	N/A	N/A	7-12	20	N/A	N/A	N/A	N/A	0.1-0.2
Fiber diameter, in.	0.004-0.016	N/A	0.008-0.016	0.002-0.016	0.004-0.008	N/A	N/A	N/A	N/A	N/A	0.001-0.003
Specific gravity	1.12-1.15	N/A	1.2-1.3	1.5	1.02-1.04	N/A	N/A	N/A	N/A	N/A	1.5
Modulus of elasticity, ksi	2750-3770	1880-3770	2175-2750	4780-5800	3770-4640	14,500	710	750	200	130	N/A
Ultimate tensile strength, psi	17,400-29,000	40,000-82,400	26,650-42,000	50,750-72,500	36,250-50,750	145,000	25,800	10,000	13,300	12,000	101,500
Elongation at break, percent	10-25	3-5	N/A	N/A	1.5-1.9	1.8-2.2	3.6	1.2	5.9	9.7	N/A
Water absorption, percent	130-180	60-70	70-75	40-45	N/A	N/A	N/A	N/A	N/A	N/A	50-75

Note: N/A = properties not readily available or not applicable.
Metric equivalents: 1 in. = 25.4 mm, 1 ksi = 1000 psi = 6.895 MPa

Table 2. Unprocessed natural fiber characteristics[75]

3. Available Synthetic Fibers

Variations of synthetic materials might be available as waste products such as any length of discarded rope, Polyethylene terephthalate (PET) from plastic bottles, or any readily shred-able plastic similar to PET or Polypropylene (PP). Although this option might not be applicable for very isolated regions affected by ERW, these waste items are often available in disaster relief humanitarian aid situations and anywhere U.S. or UN forces are present.

To facilitate the shredding of the plastic, several simple machines and hand tools have been developed specifically for the undeveloped and developing-world to make use of these waste items. Of the hundreds of PET studies and PET fibers analyzed, one of studies states, "Applicable [PET] fibers with a length of 60-90 mm and width 1-2mm"[76] are ideal, which concurs with other studies and demonstrates these processed waste items

[75] Committee 544, "State-of-the-Art Report on Fiber Reinforced Concrete: ACI 544.1R-96."

[76] Vladimíra Vytlačilová, "The Fiber Reinforced Concrete With Using Recycled Aggregates," *International Journal of Systems Applications, Engineering & Development* 5, no. 3 (2011): 363.

can be integrated in the construction methodology and possesses the same relative performance characteristics as industrial grade fibers.

Figure 14. PET fiber and test blocks from Vytlačilová study.

Samples	Compressive strength	Tensile splitting strength	Modulus of elasticity	Flexural strength
PET 1	28.67	3.07	-	2.61
PET 2	27.36	3.23	-	2.57

Table 3. Selected mechanical-physical characteristics of the PET fiber reinforced concrete from Vytlačilová study.

Fiber type	Equivalent diameter, in. x 10^{-3}	Specific gravity	Tensile strength, ksi	Elastic modulus, ksi	Ultimate elongation, percent	Ignition temperature, degrees F	Melt, oxidation, or decomposition temperature, degrees F	Water absorption per ASTM D 570, percent by weight
Acrylic	0.5-4.1	1.16-1.18	39-145	2000-2800	7.5-50.0	—	430-455	1.0-2.5
Aramid I	0.47	1.44	425	9000	4.4	high	900	4.3
Aramid II†	0.40	1.44	340	17,000	2.5	high	900	1.2
Carbon, PAN HM‡	0.30	1.6-1.7	360-440	55,100	0.5-0.7	high	752	nil
Carbon, PAN HT§	0.35	1.6-1.7	500-580	33,400	1.0-1.5	high	752	nil
Carbon, pitch GP**	0.39-0.51	1.6-1.7	70-115	4000-5000	2.0-2.4	high	752	3-7
Carbon, pitch HP††	0.35-0.70	1.80-2.15	220-450	22,000-70,000	0.5-1.1	high	932	nil
Nylon‡‡	0.90	1.14	140	750	20	—	392-430	2.8-5.0
Polyester	0.78	1.34-1.39	33-160	2500	12-150	1100	495	0.4
Polyethylene‡‡	1.0-40.0	0.92-0.96	11-85	725	3-80	—	273	nil
Polypropylene‡‡	—	0.90-0.91	20-100	500-700	15	1100	330	nil

*Not all fiber types are currently used for commercial production of FRC.
†High modulus.
‡Polyacrylonitrile based, high modulus.
§Polyacrylonitrile based, high tensile strength.
**Isotropic pitch based, general purpose.
††Mesophase pitch based, high performance.
‡‡Data listed is only for fibers commercially available for FRC.
Metric equivalents: 1 in. = 25.4 mm; 1 ksi = 6.895 MPa; (degrees F - 32)/1.8 = degrees C.

Table 4. Synthetic fibers characteristics[77]

4. Reinforcements

Like cements, natural wood and wood like materials, such as bamboo, have been used for centuries to build structures. Recently, extensive research has been done on using bamboo as a suitable replacement for structural steel concrete reinforcements, such as re-bar. Additionally, wood timbers of varying sizes have been used in Adobe structures and to reinforce rammed earth walls in places like Afghanistan for centuries.[78] The same structural properties that make these building materials desirable for structures, allow them to fit perfectly into the design requirements.

Manmade products like tires, which are often a disposal problem even in the developing-world, can be re-used as structural reinforcement, and are already widely used as improvised protective works throughout the world. Also, any resilient manmade material that can be manipulated into the design framework falls within the design requirements, as long as the reinforcement itself is secured in the structure in a manner that does not allow it to become secondary fragmentation.

[77] ACI Committee 544, "State-of-the-Art Report on Fiber Reinforced Concrete: ACI 544.1R-96."

[78] Ibid., 66–67.

5. Dry Quenching Materials

Dry quenching materials are not a structural design requirement, but as an attenuating material, it is of significant value to the overall ERW threat mitigation effort. Products, such as perlite and vermiculite, possess unique qualities that will significantly enhance the capability of any structural design. They are most commonly used as a lightweight aggregate in the construction industry and as soil amendments. Perlite and vermiculite are widely availably throughout the world and at little cost.[79] The product BlastWrap mentioned in Chapter IV uses a mixture of chemicals absorbed into perlite and sealed into plastic cells to mitigate the effects of an explosion. Without violating the BlasWrap patent, the use of untreated, loose attenuating materials, such as perlite and vermiculite, are very useful in mitigating the effects of an explosion. By simply surrounding an item with the attenuating material, the blast wave and thermal effects of an explosion can be mitigated, as the material absorbs the shock of the explosion, it will decrease the velocity of any fragmentation and lessen its lethality.

If these attenuating materials are not available, soil in small clumps or granules may be a suitable substitute. Also, rough or course fibrous material, such as unprocessed coconut husk, may be used to surround and stabilize the ERW. Any of the aforementioned fibrous materials will serve as suitable attenuating materials.

C. MATHEMATICAL SIMULATION

1. Introduction to the Simulation

Based on the characteristics of cementious fiber reinforced building materials, the aforementioned building techniques fall within the design requirements. However, the required thickness of the structure walls still needed to be determined. Figure 15 displays the required thickness of 4,000 psi concrete needed to stop primary fragmentation perforation from various ordnance diameters and items. Although the ERW-CP will be constructed using materials resembling concrete, it will not be “4000 psi concrete.” Also,

[79] Roskill, “Ultra-Light Weight Aggregates: Global Industry Markets and Outlook,” 1st. ed., September 31, 2011, http://www.roskill.com/reports/industrial-minerals/ultralightweight-aggregate.

these thicknesses are for the prevention of frag perforation at HFDR, which could be several hundred feet.[80] By using a mathematical simulation, a baseline thickness was derived to begin field experimentation of the ERW-CP.

Table 3-12. Minimal Material Thickness to Prevent Primary Fragment Perforation (Material Located at the HFDR)[1]

Description	4000 psi concrete (thickness to prevent spalling) Inches	Mild Steel Inches	Aluminum Inches	Plexiglass Inches	Bullet Resistant Glass Inches	Sandy Soil Inches
Projectiles and Bombs:	(Millimeters)	(Millimeters)	(Millimeters)	(Millimeters)	(Millimeters)	(Millimeters)
≤ 81-mm	4 (102)	0.7 (18)	1.5 (38)	4.01 (102)	3 (76)	17.3 (439)
> 81-mm ≤ 8-inch	10 (254)	1.8 (46)	3.4 (86)	7.01 (178)	4.59 (117)	36.39 (924)
> 8-inch ≤ 18-inches	18 (457)	3.13 (80)	6.03 (153)	10.7 (272)	10.19 (259)	61.4 (1,560)
Miscellaneous						
M16A1 Landmine, APERS	4.85 (123)	0.89 (23)	1.87 (47)	3.66 (93)	2.97 (75)	17.13 (435)
M21, Landmine, AT	5.20 (132)	0.79 (20)	1.74 (44)	2.37 (60)	2.25 (57)	12.36 (314)
M39, Grenade, APERS	0.31 (8)	0.05 (1)	0.11 (3)	0.37 (9)	0.24 (6)	1.3 (33)

1 Does not include shaped charge borne projectile perforation.

Figure 15. Minimal thickness of 4,000 psi concrete to stop primary fragmentation[81]

A brief introduction to the materials, system and units used to conduct the simulation is required to understand the intent and results. The materials required to meet design requirements need to have high elastic modulus[82] properties to "catch" fragmentation. They also need to be stiff enough to redirect the blast and thermal effects of an explosion. One way to test the physical properties of a material is Young's modulus. Young's modulus is a measure of the stiffness of an elastic material and is a

80 Naval Explosive Ordnance Disposal Technology Division, "Protection of Personnel and Property," 77.

81 Ibid.

82 Elastic modulus is the mathematical description of a substance's tendency to be deformed elastically when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region

quantity used to characterize materials. It is defined as the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's Law[83] holds. Young's modulus can be experimentally determined from the slope of a stress-strain curve created during tensile tests conducted on a sample of the material.[84]

The physical property data sets of the materials selected to run the simulation are on opposite ends of the materials performance spectrum. Shock absorbing concrete, the ideal material, on one end, and a material commonly referred to as Papercrete, on the other.

2. Materials Tested

The first data set comes from a study conducted by the Army Corps of Engineers. The study was done to determine the fragmentation collection properties of foamed fiber-reinforced concrete or shock-absorbing concrete (SACON). Different versions of SACON were tested consisting of the synthetic fibers: stainless steel, polypropylene, and fiberglass. Once the fibers are added, the fiber reinforced concrete is then foamed to create persistent air bubbles that aid in absorbing shock.

> The cellular structure of this type of concrete permits incoming bullets and fragments to bury themselves in the concrete without producing ricochets. Recent work on using foamed concrete in firing ranges has also shown that thick blocks of SACON can resist penetration from fragment impacts that occur at a single point beyond what might be predicted based on single projectile penetrations.[85]

The second data set comes from a study done by the University of Arizona. The scope of the project focuses on the compressive properties of Papercrete, a material made from various types of cellulose fibers (paper pulp), various types of pozzolans (cement), and water. In addition to the compressive properties, a limited number of preliminary

[83] Hooke's law, in simple terms, says that strain is directly proportional to stress.

[84] Materials Science & Engineering Dictionary, ed. Justin McCarthy, "Babylon Information Platform," 2011, http://www.engineering-dictionary.org/Materials-Science-and-Engineering-Dictionary/.

[85] Philip G. Malone and Joe G. Tom, "Foamed, Fiber-Reinforced Concrete as A Fragment Collecting Medium," Engineering, Concrete and Materials Division, U.S. Army Waterways Experiment Station, Army Corps of Engineers, Vicksburg, 1998.

tests were performed. The objective of the tests was to gain some insight on other properties, such as creep, pull and fire resistance. The objectives were as follows.

> 1. Determine a working Young's modulus (E) of the different samples in order to choose the ideal mixture that has the higher stiffness and lower deformation.
>
> 2. Study the deformation (creep) behavior of the selected samples under the application of constant load applied for a long period of time.
>
> 3. Determine some thermal properties such as thermal conductivity (K), and thermal resistance (R).
>
> 4. Determine the bond characteristics of the material by doing pull-out test.[86]

3. Simulation

Using mathematical simulation modeling, it is possible to examine the probable properties of various Papercrete mixes and compare them to the probable performance properties of SACON.

4. Shock Absorbing Concrete (SACON)

SACON possesses ideal material properties desirable for the design parameters as shown in Figure 16. However, the process to make SACON is complex, expensive and requires specialized equipment. Therefore, SACON requirements are not conducive to the design requirements for construction.

[86] University of Arizona, The Center for Alternative Building Studies, "Papercrete Engineering Research Report, 2005, 9.

Figure 2 shows the apparent depths of penetration for a low-density, steel fiber-reinforced block (Test Block 50 steel) and for a low-density, polypropylene fiber-reinforced block (Test Block 50 polypropylene). After 10 shots were fired the hole in the polypropylene-reinforced block was approximately 30 percent deeper than the hole in the steel-reinforced block.

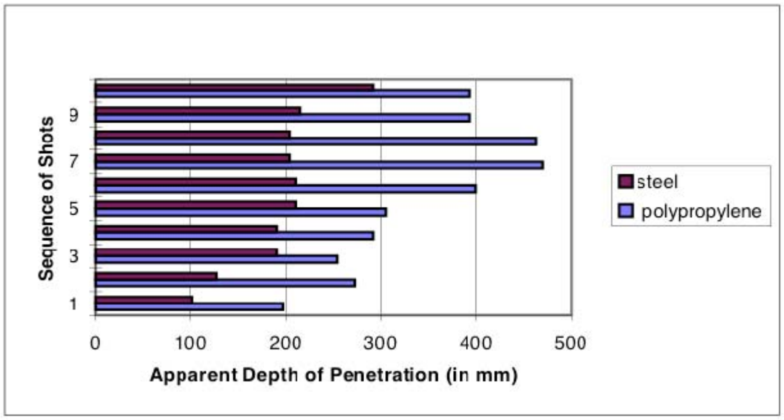

Figure 2. Comparison of the penetration of 10 single shots in samples of 800 and 915 kg/m^3 (Series 50) SACON blocks with polypropylene fiber and steel fiber reinforcement.

Figure 16. Results from Army Corps. of Engineer's SACON test[87]

1 millimeter = 0.03937007874 inch

0.039370079

mm	inch
100	3.937007874
200	7.874015748
300	11.81102362
400	15.7480315
500	19.68503937

Figure 17. Millimeter to inches conversion

[87] Malone and Tom, "Foamed, Fiber-Reinforced Concrete as A Fragment Collecting Medium," 5.

Properties of SACON Used in this Investigation				
Block Series	Density (Kg/m3)	Unconfined Compressive Strength (MPa)	MPa AVG.	MPa to psi
70 steel	1,236	2.8-3.5	3.15	456.87
60 steel	1,080	2.7-2.9	2.8	406.11
50 steel	915	2.1-2.4	2.25	326.33
50 polypropylene	800	2.1-2.4	2.25	326.33
1 megapascal (MPa) = 145.037738 pounds per square inch (psi)				
145.037738				
			2.1	304.58
			2.2	319.08
			2.3	333.59
			2.4	348.09
			2.5	362.59
			2.6	377.10
			2.7	391.60
			2.8	406.11
			2.9	420.61
			3	435.11
			3.1	449.62
			3.2	464.12
			3.3	478.62
			3.4	493.13
			3.5	507.63
			42	6091.58
			2.8	406.11

Figure 18. Properties of SACON[88]

Data from Figure 18 is used to run the first simulation. By developing 1,000 iterations of random numbers between the top 507.63 psi and the bottom 304.58 psi of the data set range and averaging them, then running the average 1,000 times again, test results can be simulated as if the actual test had been conducted 1,000,000 times. The simulation resulted in an average materials performance of 405 psi uniformed compressive strength, with a Bin between 399 psi and 411 psi. The low end representing the polypropylene reinforced SACON and the high end representing the steel reinforced SACON.

[88] Malone and Tom, "Foamed, Fiber-Reinforced Concrete as A Fragment Collecting Medium," 3.

304					
507					
315			1	405.8641	59.70792
451	average	407.4885	2	406.1179	58.16288
398	std	59.67913	3	405.1888	57.98153
493			4	408.3397	58.3743
313			5	407.1828	59.96951
332			6	406.8521	58.75117
346			7	402.8841	59.04453
363			8	404.6364	58.98052
304			9	403.3626	58.63162
311			10	405.02	56.91762
399			11	405.8611	57.62477
482			12	404.8731	58.91982
314			13	405.1748	58.76731
416			14	408.4186	58.96448
414			15	404.4925	58.68535
364			16	408.2587	59.98471
437			17	406.4755	58.41208
392			18	405.7493	58.76901
335			19	404.5465	60.02066
356			20	401.7862	59.27192
402			21	408.4615	59.45797
499			22	404.2298	59.83978

Figure 19. Screen shot of Excel simulation

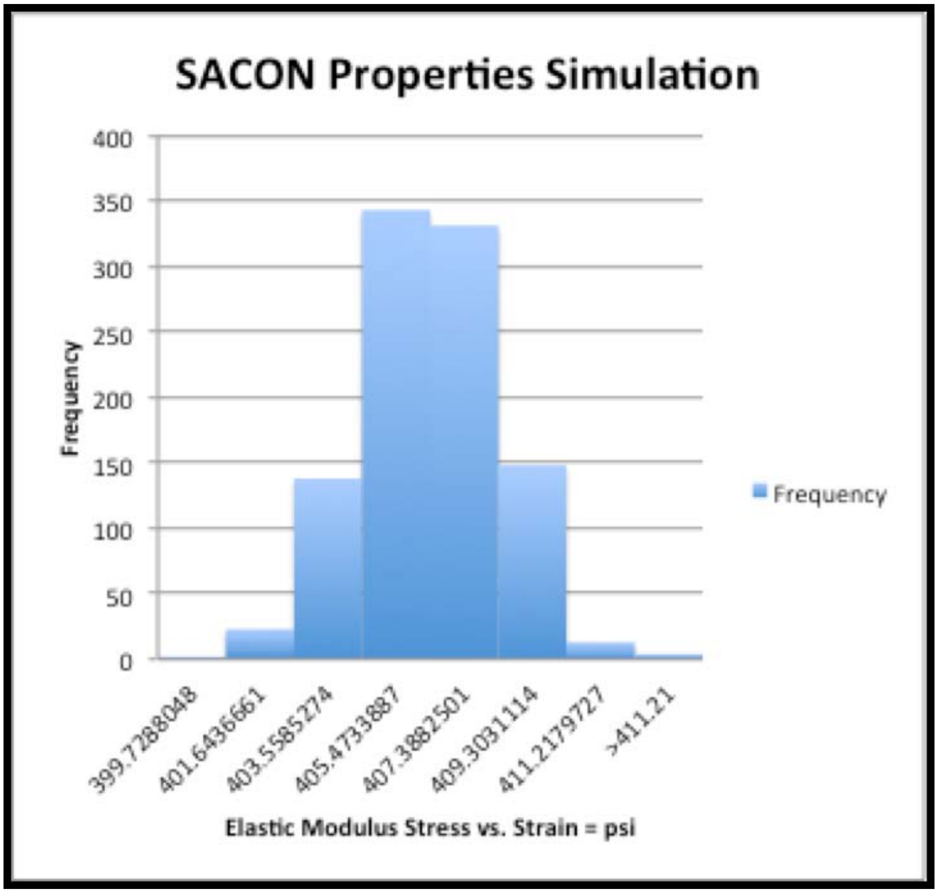

Figure 20. Histogram of SACON simulation

5. Papercrete

The second data set comes from the University of Arizona Papercrete report. The same simulation process was run on the materials test results for the different mixes of Papercrete. Figure 21 shows that the variety of mixes and their subsequent test results are significant, in that they should closely represent the varied mixes and conditions that could be encountered where possible solutions will be constructed throughout the world.

Properties of Papercrete Used in this Investogation				
Sample	Material	Proportions	Elastic Modulus 1 / L vs. D = psi	Elastic Modulus 2 / S vs. S = psi
Sample1	Paper/Portland	1-1	600	200
Sample2	Paper/Portland	1-2	1200	560
Sample3	Paper/Portland	1-3	2000	860
Sample4	Paper/Portland/Sand	1-1-5gal	800	285
Sample5	Paper/Portland/Sand	1-1-10gal	700	330
Sample6	Paper/Portland/Sand	1-1-15gal	590	280
Sample7	Paper/Portland/Fly Ash	1-.7-.25	950	260
Sample8	Paper/Portland/Fly Ash	1-.6-.30	420	190
Sample9	Paper/Portland/Fly Ash	1-.5-.35	400	200
Sample13	Paper/Portland/Styrofoam	15% Sty	1200	700
Sample14	Paper/Portland/Styrofoam	20% Sty	1430	490
Sample15	Paper/Portland/Styrofoam	25% Sty	850	490
Sample16	Sludge/Port./Fly	1-.7-.25	1390	
Sample17	Sludge/Port./Fly	1-.6-.3	2700	
Sample18	Sludge/Port./Fly	1-.6-.3	2700	
Sample19	Paper/Portland/Glass	1-1-5gal	470	200
Sample20	Paper/Portland/Glass	1-1-10gal	570	250
Sample21	Paper/Portland/Glass	1-1-15gal	700	230
Sample22	Paper/Clay	0%Port	1394	620
Sample23	Paper/Portland/Clay	1 bag mix	855	390
Sample24	Paper/Portland/Clay	2 bag mix	1375	670
Sample25	Paper/Portland/Lime	1-.5-.5	400	170
Sample26	Paper/Portland/Lime	1-1-1	570	230
Sample27	Paper/Portland/Lime	1-1.5-1.5	650	250
Sample30	1/8 inch grind	1:2	1550	
Sample33	3/8 inch grind	1:2	2000	
Sample35	5/8 inch grind	1:2	1200	
Sample36	Clyde T. Curry: Poured 2/13/05	Per yard	1250	100
Sample37	Zach Rabon:Poured on 2/5/05	Per yard	3000	800
Sample60	Cardboard Pour 3/17/05	.7 yard	220	
Sample38	Paper/Port/Fly ash/Sand	200 gal	1200	100
Sample39	Paper/Port/Fly ash/Sand	200 gal	900	120
Sample40	SRP Printing paper	0.7	1500	270
Sample41	Mixed waste paper	1/2 batch	1300	
Sample42	Paper/Port/Fly ash/Sand	0.7	2100	220
			41154	9465
			Elastic Modulus 1 psi AVG.	1143.166667
			Elastic Modulus 2 psi AVG.	338.0357143

Figure 21. Properties of Papercrete[89]

Data from Figure 21 is used to run the second simulation. By developing 1,000 iterations of random numbers between the top 860 psi and the bottom 100 psi of the data set range and averaging them, then running the average 1,000 times again, test results can be simulated as if the actual test had been conducted 1,000,000 times. The simulation resulted in an average materials performance of 480 psi uniformed compressive strength, with a Bin between 459 psi and 500 psi. The low end represents mixes with less Portland

[89] University of Arizona, The Center for Alternative Building Studies, "Papercrete Engineering Research Report, 2005, 3–5.

cement and cellulose fiber reinforcement and more alternative pozzolans. The high end represented mixes with higher Portland to aggregate and reinforcement ratios.

Compared to the fibers that are prominent throughout the world, such as hemp, jute and coir, paper fibers have relatively low tensile strength. Using the results of the lowest preforming fibers to run the simulation allows for even greater confidence.

ç							
	860						
	100						
	706			1	485.6913	217.9769	Bin
	664	average	485.6913	2	498.2737	222.81	459.6309
	717	std	222.2393	3	487.6743	218.2737	466.4444
	578		1	4	480.6543	222.7657	473.2579
	478			5	495.9181	219.6957	480.0713
	668			6	492.3267	214.138	493.6983
	509			7	481.6553	219.3377	486.8848
	169			8	467.6873	223.577	500.5118
	200			9	487.4046	224.2836	
	800			10	494.7083	219.5371	
	530			11	490.6753	222.5927	
	795			12	476.973	219.7336	
	220			13	487.3776	221.628	
	462			14	486.7522	223.5447	
	556			15	479.5554	217.6134	
	625			16	481.988	222.2181	
	291			17	488.1159	217.389	
	209			18	468.7273	216.93	
	645			19	477.7522	218.8102	
	341			20	471.3397	221.3393	
	525			21	482.4995	222.7082	
	475			22	472.3606	221.0286	

Figure 22. Screen shot of Papercrete simulation

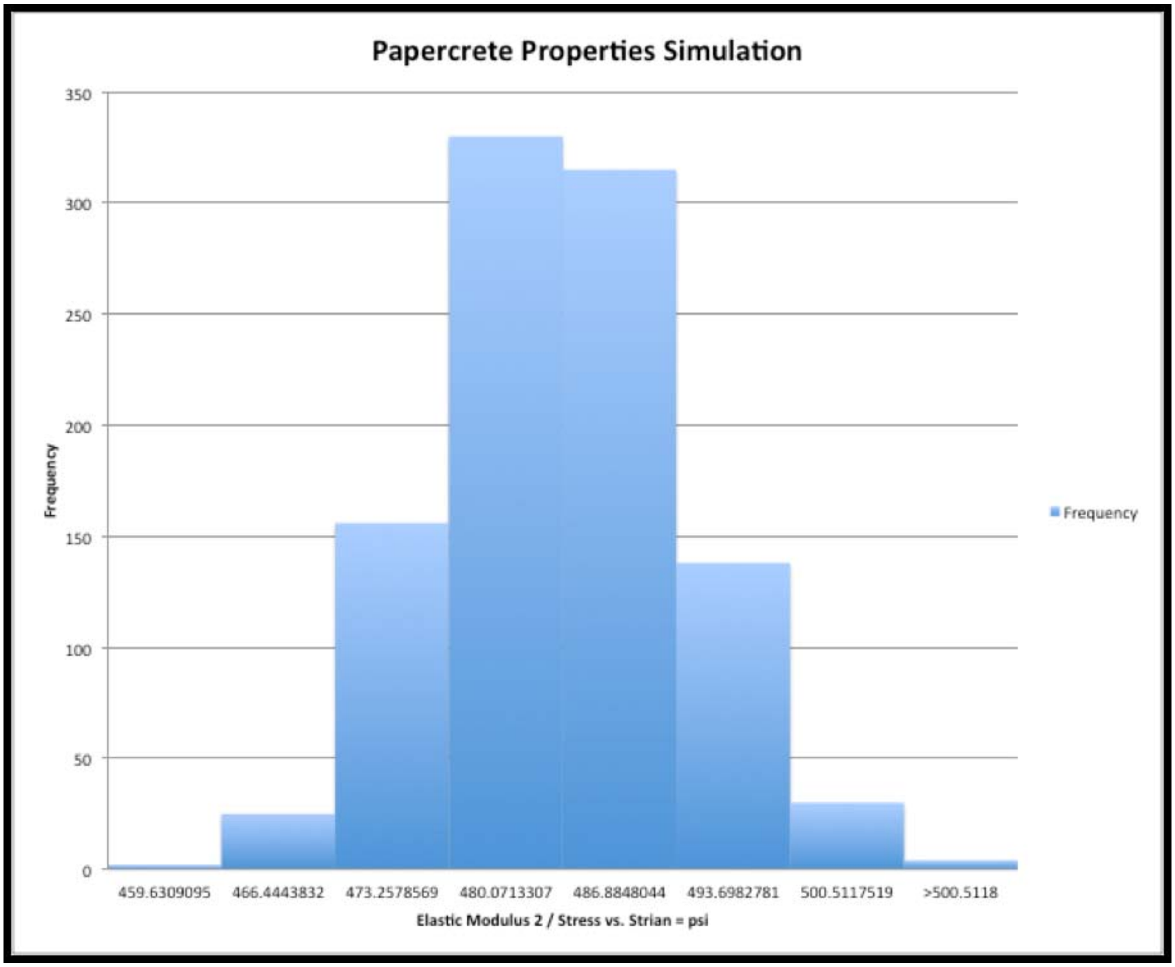

Figure 23. Histogram of Papercrete simulation

6. Summary

Based on the two simulations, the probability of SACON and Papercrete materials performance can be predicted. On average, SACON stress vs. strain elastic modulus is 405 psi. According to the SACON test, SACON with an average elastic modulus of 405 psi will have a high probably of stopping a round fired from a M16A2 rifle firing the 5.56 mm NATO Ball M855 round at a depth between seven and eleven inches. The M16A2 has a velocity of 990 to 1,000 m/s. The purpose of a 5.56 round is to penetrate deep into the target and fragment. Fortunately, fragmentation from an exploded fragmentation producing round, such as a 60 mm mortar round, is designed to rip and tear through its

target traveling at much slower speed. As a result, fragmentation has a lower target penetration. These characteristics of fragmentation are advantageous to the design concept.

Papercrete's average materials performance was 480 psi uniformed compressive strength, with a Bin between 459 psi and 500 psi. The simulation predicts that, on average, Papercrete's material performance is comparable to that of SACON.

The data from these simulations allows the thickness of the walls intended to stop fragmentation to be determined with relative predictability without doing preliminary field tests. Using the simulation data as a base line, preliminary construction design parameters will require seven to 10-inch walls to begin field experimentation. These simulations do not include the use of attenuating materials, such as perlite and vermiculite. The addition of these materials will increase the effectiveness of the structure walls.

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VIII. MEETING THE DESIGN REQUIREMENTS

A. EXPLOSIVE REMNANTS OF WAR–COLLECTION POINT (ERW-CP) DESIGN

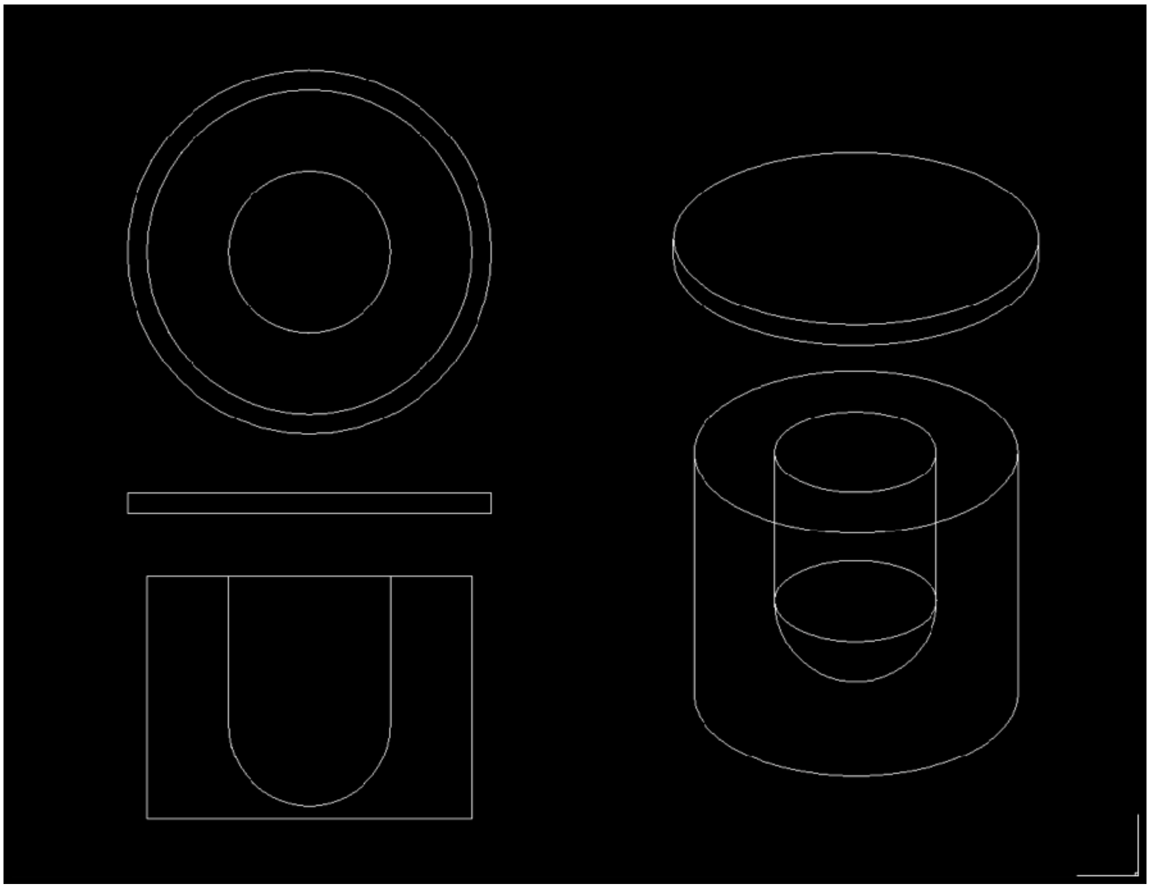

Figure 24. Explosive Remnants of War-Collection Point design concept

1. Development

The current design is an attempt to meet the established design requirements previously, developed after several years of first-hand experience and general analysis of the global ERW problem. After recognizing the ERW disposal and storage management capabilities gap existed at the lowest local levels, largely due to resource constraints, it was determined that local solutions were required.

The structure as designed will provide safe, secure, temporary storage of ERW at the lowest level. The structure is scalable, reproducible, and once constructed, will be clearly marked and easily accessible to the local ERW affected population. Testing will confirm that the structure will provide an acceptable level of protection from unintended ERW detonations. Finally, the building technique allows for easy construction by locals using primarily locally sourced building materials at little to no cost to the local population. The design has evolved considerably from a simple lockable box to the current cylindrical design.

The universal approach to mitigating the effects of an explosion is a structure built of thick metal, and or a reinforced building material, in which the explosion is vented out the top of the structure. From the beginning of the design process, this concept has been maintained. It also provides an effective way to vent explosive forces up and away from the population while providing a way to secure ERW items within the structure.

The unique design of the ERW-CP was developed with the understanding that explosive reactions will exploit any weakness in any material by taking the path of least resistance. Compounded with the reaction's inability to make sharp turns, results in the reaction have nowhere else to go and "over-pressurize" containment and mitigation vessels.[90] Most blast protection and mitigation structures overcome this limitation by using very thick of very strong ideal building materials. However, in keeping with the design requirements, using what is locally available and less than ideal, a different approach was required.

The cylindrical structure and hemispherical shape of the internal base allows the chemical reaction of the explosion to take the path of least resistance, up and out, without having to turn around in any corners. These design features in combination with natural fiber reinforced building material properties allows for the use of less than ideal building materials.

[90] *Blasters Handbook*, 341.

Although reinforced structural concrete is used prominently throughout the world, it is not a cost effective ERW mitigation option on the scale needed to address the ERW management gap. A look at developing-world building solutions already being implemented informed the proposed design. The use of locally sourced material and techniques eliminate, or significantly reduce, costs and logistical requirements. Through the research conducted, it was confirmed that naturally occurring cellulose fibers possess comparable reinforcing qualities to synthetic fibers at considerably less cost. It was also confirmed that natural structural reinforcement, such as bamboo, when applied properly, could perform as structural reinforcements, and waste, such as discarded tires, are a viable structural reinforcement that enhance design performance.

B. BUILDING MATERIALS

1. Sourcing

Design requirements dictate that building materials be sourced at the local level. The current design is based on this concept. By using the predominate local fiber in conjunction with the locally available cement product or substitute, a suitable fiber reinforced building material can be produced. The spectrum of applicable building techniques range from fiber reinforced soil cements to fiber reinforced Portland-pozzalan based mixtures. As such, for the purpose of this section, fiber reinforced building materials will be referred to as FRBM.

If individual elements of the FRBM cannot be purchased already prepared within cost limitations at the local level, the following adjustable standards can be referenced.

2. Cements

As referenced in Chapter VII, the location and circumstances at the local level will dictate which cement and technique will be used. If cement cannot be sourced locally, organizations providing assistance should be able to purchase materials at little cost. For the purposes of testing, variations of the soil cement technique and variations of the Portland-pazzalon cement technique were used.

3. Fibers

Again, the location and circumstances at the local level will dictate which fiber and technique will be used. Regardless of fiber type, the optimal fiber length range is between 1/2”–2” separated from adjacent or connected fibers as much as possible, which can be accomplished in a number of ways and should ideally use the preferred local method. If no local method for processing fibers is available, several options are that can be locally fabricated and implemented, such as screen-less hammer-mills. The ERW-CP prototypes were constructed with both chopped fibers and raw fibers sourced from cedar bark. Chopped cedar bark closely represents Jute or Hemp fibers while raw cedar bark closely resembles Coir and sugarcane fibers.

4. Reinforcements

To meet design requirements, ideally, vertical and horizontal structural reinforcements will be locally sourced and limited only to the imagination of the builders and availability. For the purpose of building the prototypes and testing, limited metal, natural wood, bamboo, and discarded tires were used. This range of materials accurately represents the anticipated range of reinforcing materials available across the globe. However, through experience, discarded tires seem to be available even in the most isolated areas of the world. If available, tires should be used as the primary form of reinforcement. If tires are unavailable, any reinforcement materials can be used as most of the structural integrity is derived from the design, and provided by the FRBM itself.

5. Structural Forms

Although not required, very simple structural forms are highly recommended to construct the ERW-CPs. Forms greatly increase the speed of construction and overall appearance of the finished structure. The flexible material required for the forms should ideally be purchased or fabricated at the local level. As per the design requirements, the construction process needs to be repeated as necessary, which requires the forms themselves be reusable. The form concept, not the form material, is important. Once the construction concept is understood, any suitable flexible form making material can be used. The forms and the construction process will be described in detail, in Appendix A.

C. CONSTRUCTION TECHNIQUE

The intent of the ERW-CP concept is to disseminate the design throughout as many ERW-affected populations as possible, which requires that all language and communication barriers be broken down. To resolve this situation, a How to Manual" and a pictographic "How To Poster" demonstrating several universally applicable construction concepts are presented in Appendix A.

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IX. CONCLUSIONS AND RECOMMENDATIONS

A. ERW AND INSTABILITY

By identifying the specific characteristics that make ERW a continuous threat and hindrance to stabilization and development, a direct correlation can be made between instability and the mismanagement of ERW. This mismanagement allows it to remain a threat to life and limb. Mismanaged ERW is not only an immediate threat; it is being used as a primary component in IED fabrication throughout the world and poses a direct threat to deployed U.S. personnel and U.S. strategic partner personnel.

The ERW management gap is caused by the relationship between the scale of ERW contamination and available ERW management capacity or limitations. Each country or region possesses specific variables that contribute to the ERW management gap. As a result of these country specific causes, efforts to mitigate that gap will, in turn, be affected by these same variables and need to be addressed on the same level.

While ERW is a global problem, “first world” ERW management approaches are not always the solution. However robust the effort to remove ERW is, it cannot all be disposed of simultaneously, or even in a timely manner. Once discovered, if not disposed of onsite, ERW requires storage. Unfortunately, in developing and undeveloped regions, improvised management techniques and structures result that do not provide adequate protection to the populace, nor do they protect the ERW from further deterioration caused by the natural elements.

Most of these situations are caused by a lack of access to knowledge and resources. At one end of the spectrum, simply digging a deep enough hole for ERW storage in every village affected by ERW is not an adequate storage solution. At the opposite end of the spectrum, building military grade facilities is unrealistic. An appropriate, and sustainable, ERW management solution is required that is simple and scalable.

B. MEETING THE ERW-CP DESIGN PARAMETERS

A structure is required that provides safe, secure, temporary storage of ERW at the village level. The structure must be scalable, readily available, and once constructed, clearly marked and easily accessible to the local ERW-affected population. The structure must provide an acceptable level of security to prevent the theft of the stored ERW. The system or structure must be easily constructed by affected populations using primarily, locally sourced building materials at little to no cost to the local population.

By applying proven alternative building construction techniques, this study demonstrates that an effective state of the art design can be implemented using non-traditional or natural structural reinforcement, in combination with natural fiber reinforced building materials by non-professional builders. Moreover, this study validates that the design is effective in mitigating the threat of mismanaged ERW by meeting the specified design requirements.

The preliminary explosive tests conducted on 10 ERW-CPs built using the suggested practices verified all ERW-CP design parameters were met or exceeded. Appendix B contains a detailed analysis of the explosive tests conducted in a laboratory environment at Lawrence Livermore National Laboratories (LLNL) High Explosive Application Facility (HEAF) and field-testing during the Joint Interagency Field Exploration (JFIX) event at Camp Roberts.

The following is a brief synopsis of the results.

1. Fragmentation

All primary fragmentation was contained or defeated. Most secondary fragmentation having an impact energy of 58 ft-lb. or greater was mitigated to a distance of 24 ft., while all secondary fragmentation was eliminated at a distance of 50 ft. Additionally, the test dummy placed at 50 ft. from all ERW-CPs received no damage, and remained undisturbed throughout the entire test series.

2. Blast

The K-24 blast overpressure mitigation level (>2.3 psi 15.9 kPa)[91] was verified during the LLNL/HEAF tests by two PCB Piezotronic 137A21 pressure sensors at a distance approx. 40" to 35" from the outside diameter of the ERW-CP. A K- 50 (> 0.89 psi) blast overpressure mitigation level was verified on five of the six shots, including a 2 lb. NEW shot. Mitigation of the blast wave during the JIFX testing was verified by observation using high definition cameras and a test dummy.

3. Thermal

All thermal effects were mitigated through structural shielding provided by the ERW-CPs in both test series. As per DoD Ammunition and Explosives Safety Standards Manual (6055.9-STD), personnel protection must limit thermal fluxes to 0.3 calories per square centimeter per second [12.56 kilowatts per square meter]. Verification was accomplished via internal thermometers in the LLNL/HEAF spherical tank. During the JIFX field tests, thermal mitigation was verified by observing the actual redirection of explosive energy via high definition cameras.

As with all designs, further testing and development is highly encouraged. However, due to the variety of construction materials the ERW-CP is designed to use, and the environments to which the ERW-CP is intended to be deployed, further development should not be geared toward any one standard. In keeping with the spirit of the project, the broadest spectrum of design dissemination and construction methodology should be maintained.

C. ERW-CP DISSEMINATION RECOMMENDATIONS

The ERW-CP design described and tested in this study implements a simple, scalable, design and construction methodology utilizing locally sourced, sustainable, and repurposed materials. Through a "train the trainer" approach, a basic "How to Manual," in Appendix A, accompanied by a completely pictographic "How to Poster," are

[91] Department of Defense, Under Secretary of Defense for Acquisition, Technology & Logistics, "DoD Ammunition and Explosives Safety Standards 6055.9-STD," 42.

presented as the preferred method of knowledge dissemination. Programs, such as Humanitarian Demining, Foreign Internal Defense and Village Stability Operations, along side international aid efforts are cited as examples of appropriate levels for disseminating the ERW-CP concept to assist in strategic partner capacity building, post conflict stabilization efforts, and the global ERW, Mine/UXO education, management, and disposal efforts.

As further evidence of both the need for this type of ERW-CP design and the validity of the design dissemination effort, both humanitarian, the U.S. State Department, and DoD organizations, such as Special Operations Command Central (SOCCENT) Burners Without Borders, Central Command (CENTCOM) United States Department of Agriculture Fragile Market Economics Division, FAF Development Group LLC, Center for Armed Warfare and Armed Groups, and e-Afghan Ag, have all requested the manual and poster for immediate employment in their respective areas of operation.

The ERW-CP concept fills the capability gap between digging a hole in the ground at the edge of an isolated village and large, professionally managed, "First World" ERW storage solutions accomplished by empowering local ERW affected populations, with <u>suitable</u> state of the art design concepts that use simple, sustainable, construction methodologies.

APPENDIX A. "HOW TO MANUAL"

A. PREREQUISITES

1. Adhering to International Guidelines for Landmine and Unexploded Ordnance Awareness Education

To implement an ERW-CP project properly, certain issues must be addressed. First, adherence to the UN's "International Guidelines for Landmine and Unexploded Ordnance Awareness Education"[92] programs must be maintained. Second, a simple, universally acceptable, procedure must be disseminated and implemented to get the ERW from the discovery site to secured areas in the ERW-CP.

First, the UN Mine/UXO awareness mantra "Don't touch it, mark it, report it,"[93] while idealistic, should be followed and must always be recommended, which may seem contradictory to the concept of a locally managed ERW collection point. However, an ERW-CP is only needed when no reliable reporting system is available above the local authority or, even when reported, the capacity to dispose of the ERW in a timely manner is not available. To adhere to the global Mine/UXO awareness programs, the ERW-CP project must hinge on following Mine/UXO awareness reporting procedures at the lowest levels of authority. However, it would be impossible not to provide a means for safely storing ERW brought in to local authorities even if one does not endorse the handling of ERW by untrained personnel.

Second, in accordance with Mine/UXO awareness efforts, after the ERW is discovered and marked, the discovering individual must report the incident to the local leader or whoever is the local reporting authority. It then falls upon that local leader to determine an acceptable course of action. If a reporting system above the local level has been established but is unable to respond in what that local leader deems an effective timeframe, the leader has an option with an ERW-CP. Once it is determined by the local leader that action must be taken, this individual assumes the risk and a simple line pull

[92] United Nations, "International Guidelines for Landmine and Unexploded Ordnance Awareness Education."

[93] Ibid.

procedure,[94] and wait time can be performed. After a successful line pull procedure, the ERW can then be transported to and secured within the ERW-CP.

2. Dissemination and Overcoming Language Barriers

The preferred dissemination technique is a train-the-trainer format though local engagement regardless of program or organization. To overcome all language barriers, this Appendix is to be used with the "How To Poster" comprised of the compiled figures used throughout this appendix.

B. MATERIALS ACQUISITION AND PREPARATION

1. Fiber Reinforced Building Material Preparation

Proper preparation of FRBM is the most important element of the design. The FRBM gives the structure its strength and allows for the design requirements to be met. Local fibers prepared in the local custom are ideal. Figure 25 provides a list of common natural fibers found throughout the world. Figure 26 provides a comparison of raw fibers, which may be used if necessary, and chopped fibers of the proper length and texture. Six to seven five gallon buckets or one 55-gallon drum full of fiber should be sufficient for one ERW-CP.

[94] A "line pull" is a procedure used to remotely move or "jar" UXO from a safe distance and under frontal and overhead protection. The procedure consists of evacuating the area of personnel and, without disturbing it, tying a line to the UXO. Once the line is around the UXO, the individual backs out to the predetermined safe distance and takes frontal and overhead protection. The individual then forcefully pulls the UXO several feet from its original resting place and waits 30 minutes to an hour. If the UXO does not detonate, it is deemed safe to move.

S Bagasse (Sugar Cane Pulp)	Phormium (New Zealand Flax)	Indian hemp (Dogbane)	Papaya
Reed Fiber	Ramie (China grass cloth)	Sisal (Often termed agave)	Coir (fiber from the coconut shell)
Palm Fiber	Bamboo fiber	Umbrella plant	Milkweed
Piña	Abacá	Cotton	Kapok
Bast fibers	Nettles	Esparto	Bowstring Hemp
Jute	Kenaf	Henequen	Hemp
Flax	Hoopvine	Elephant Grass	Yucca (An agave)
Water Reed	Plantain	Musamba	Wood Fiber (kraft pulp)
Maguey	Lechuguilla	Banana Leaf	Guaney

Figure 25. Natural Fibers

Figure 26. Chopped fibers 1/2”–2” (1.5–5 cm) compared to raw fibers

a. *Cements/Soil*

Any Portland cement will suffice, as will any alternative pozzalan, such as RHA or Fly Ash. Two to three 90 lbs. bags of cement should suffice. However, if

available, the more cement used the stronger the ERW-CP will be. Likewise, any earth will suffice. However, some soil properties are preferred. such as clay and sand content. The local population should know the soil content and suitability. Ideally, top-soil is not desirable for use due to the abundance of organic material. If necessary, dig into the side of a hill or down a few feet to reach the proper soil. However, a dampened soil sample can be balled upm and it holds together well without crumbling or cracking, it is suitable. If it is possible to roll out the soil and form it into a horseshoe shape without breaking, it has high clay content and is considered ideal.

To ensure the proper soil consistency is reached, separate the larger aggregate (rocks) from the soil with a simple, large soil sieve or the preferred local method. A four ft. (one 1/2 meter) diameter pile approximately three ft. (one meter) high should supply enough soil for one ERW-CP.

b. Mix Quantities and Ratios

The ERW-CPs are constructed using equal parts by volume of fiber and cementious matrix mix. Although fiber ratios for making traditional building products, such as straw reinforced adobe are much less, usually around 5–10%, regular building materials are not intended to mitigate explosions.

Whether mixing the fiber into a Portland cement matrix or a soil cement matrix, it is essential that the fiber and the cementious matrix be dry mixed thoroughly to allow the fibers and the cementious matrix be evenly distributed without clumping together. The result should be completely “cement dust” covered fibers. Water is added later in limited quantities until the proper “mud” consistency is reached. The mixing is done by whatever means is common to normal cement/concrete building techniques. However, if no local techniques exist, the mixing can be done in batches on a mixing tarp or directly on the ground with simple hand tools, which is covered again in detail.

2. Reinforcement Prep

a. Tires

If unserviceable truck tires are available, they should be used as the optimal ERW-CP reinforcement. Tire reinforced ERW-CP structures are unique, in that the tires serve as both the horizontal and the vertical structural reinforcement, and drastically reduce construction materials and time.

Large truck tires are preferred as they provide a larger Inside Diameter (I.D.), or rim size. However, if no truck tires or large rimed tires are available to accommodate a 20–24 inch (50–60 cm) I.D., smaller tires can be used. Figure 27 demonstrates removing the sidewalls of smaller tires and cutting the tires vertically in one spot. The tire treads can be made into strips and then woven through vertical reinforcements to form a very strong "tire basket" that will serve as the reinforcement. The basket method is described in detail later.

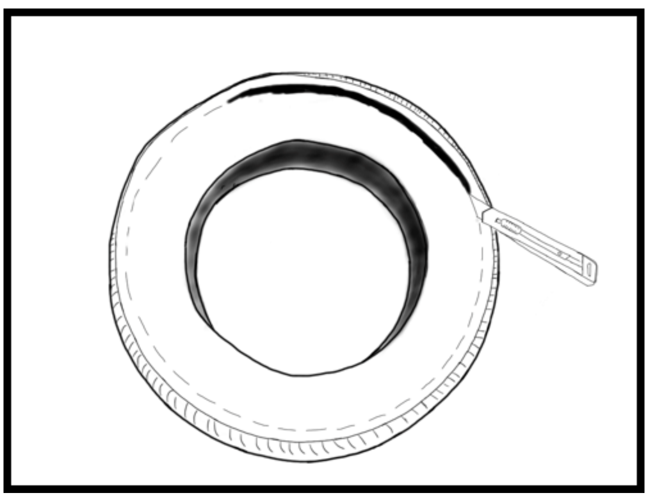

Figure 27. Tire prep

b. Vertical Reinforcements

If no tires are available, other structural reinforcements can be used. All other vertical reinforcements regardless of material should be as strait as possible and a

minimum of approximately 3 ft. (approx. one meter). If available, bamboo is highly recommended. Whatever material the local population is able to produce will be suitable.

Vertical reinforcements can vary in diameter; however, reinforcements should be approximately 1/2" (1.27 cm) and no smaller than 1/4" (.635cm) in diameter. The vertical reinforcements will act as the framework for the horizontal reinforcements. A minimum of eight vertical reinforcements is recommended for each ERW-CP. However, the number of reinforcements is subject to availability and weaving material. The thicker or stiffer the horizontal weaving material, such as tire strips, the less vertical reinforcements can be used. The thinner or more flexible the horizontal weaving material, such as bamboo strips, the more vertical reinforcements can be used.

c. Horizontal Reinforcements

Horizontal reinforcements regardless of material should be secured or interwoven onto or into the vertical reinforcements as best as possible. As stated, horizontal reinforcements can consist of any material with substantial tensile strength including wastes products, such as plastic bags and bottles cut into strips. Tire or bamboo strips are highly recommended, but any material used to weave local baskets will suffice.

3. Inside Diameter (I.D.) Form Preparation

To withstand the weight and pressure of the FRBM against the I.D. form, it needs to be ridged. A ridged core wrapped in a thick plastic sheet is recommended. This configuration allows the FRBM to set around the I.D. form while allowing the form to be removed easily and reused. However, in keeping with design requirements, any system that can be devised following this concept can be used, as long as the I.D. surface is relatively smooth and is no smaller than 20" (50.8 cm).

4. Ground Prep

Very little ground prep is required. The most import aspect of ground prep is site location. The ERW-CP site must be within the complete control of the local population, preferably within view of the established local authorities, out of high traffic areas to allow access to the ERW-CP, yet provide a layer of security. If possible, maximize the

distance of the ERW-CP from inhabited areas while maintaining purview over the site. A 50 ft. (15.24) circle of uninhabited space should surround the ERW-CP. If the level of ERW contamination is suspected or is known to be high, a site should be chosen that would allow for several ERW-CPs to be constructed within close proximity. A 50 ft. (15.24m) is not required between ERW-CPs, as little risk of sympathetic detonation exists should an ERW item unintentionally detonate within an adjacent ERW-CP. However, sufficient space to allow easy of movement between ERW-CPs is recommended.

The site should be as level as possible, on stable soil and clear of debris. A level six ft. (2 m) area is more than sufficient for the ERW-CP structure. However, additional workspace is recommended.

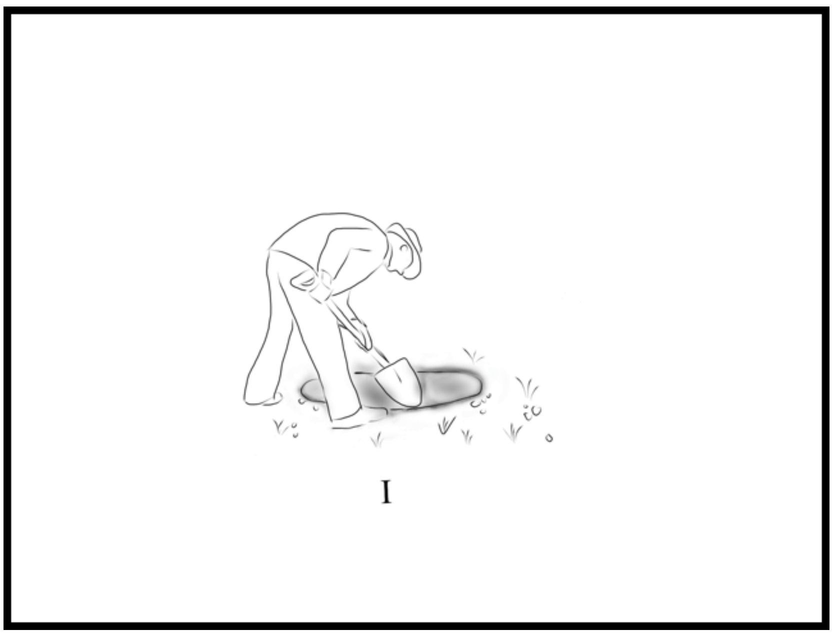

Figure 28. Ground preparation

C. BUILDING THE ERW-CP

Once all FRBM, horizontal and vertical reinforcement, form and ground perpetrations have been made, construction can begin. Two versions of the ERW-CP with distinct construction techniques exist. the “tire” ERW-CP, and the “basket” ERW-CP.

IMPORTANT

FOLLOW THIS DRY MIXING PROCEDURE

It is important to follow this dry mixing procedure to ensure the binding agents properly and completely coat or encapsulate the fibers. The material ratios are very simple and can be scaled appropriately. At a minimum, 1/2 bucket of cement added to one bucket of fiber and dry mix together. Then add one bucket of soil to the cement and fiber mix and dry mix together. Followed by adding 1/2 bucket of sand to the cement, soil, and fiber mix, and dry mixed again. Figure 29 provides an example. It is understood that a five-gallon bucket will not always be available. Based on this assumption, it is important to remember that the ratios are the most important factor as opposed to the actual volume amounts.

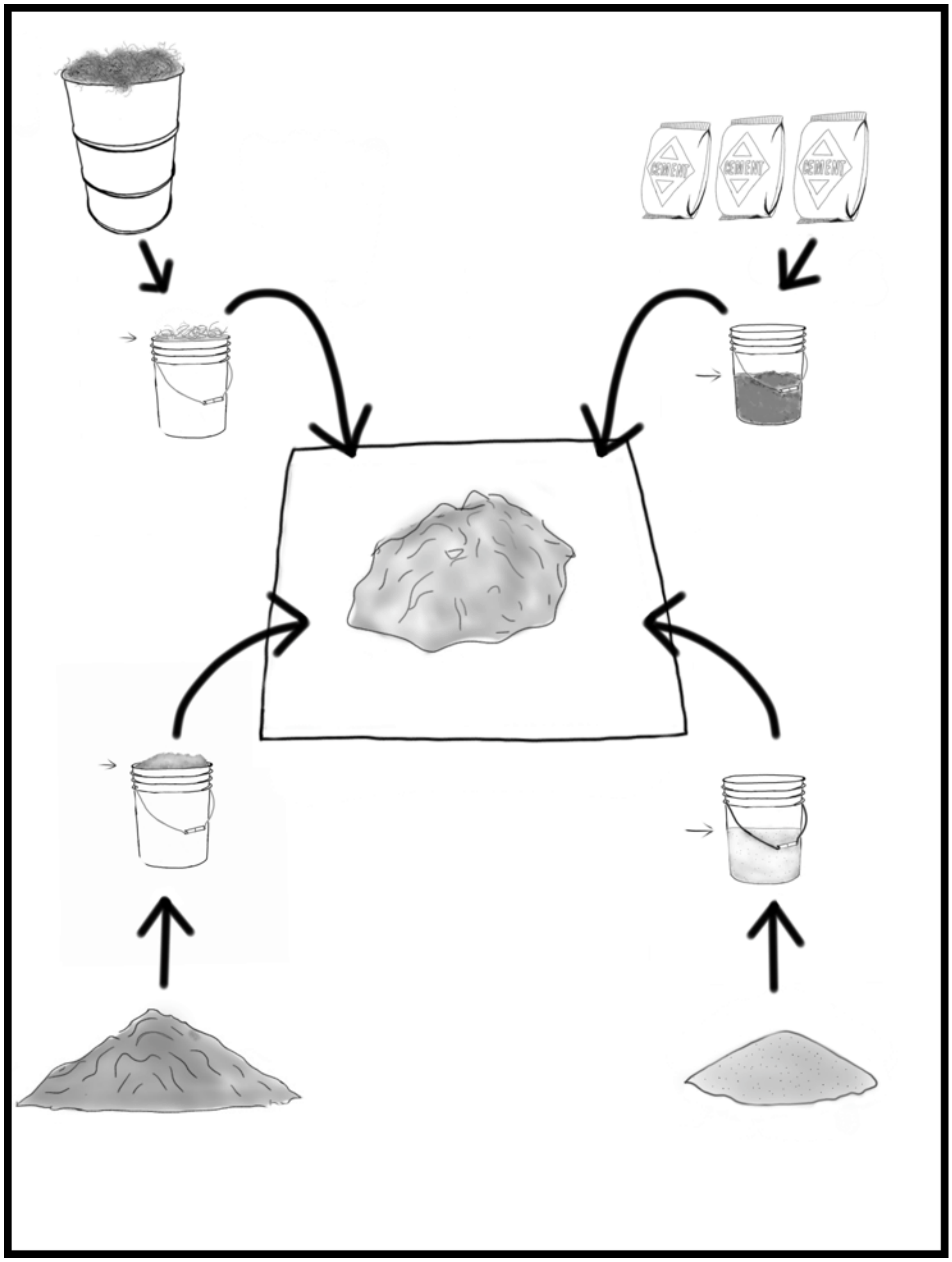

Figure 29. Sample FRBM dry mixing ratios pictograph based on five-gallon bucket and mixing tarp

After the dry mixing procedure has been followed, and the fibers are completely coated or "dusted" in the binding matrix, water can be added in small amounts until the desired mud consistency is reached.

1. Tire Reinforced ERW-CP

If using whole tires, the tires will be stacked three to four high, (approximately 1 ft. feet or 1 m high) and filled with FRBM. The recommended method is to place the initial tire in the middle of the prepared site. Form a base layer or FRBM inside the tire directly on the ground. Continue packing the tire with FRDM while forming the hemispherical bottom as shown in Figure 30.

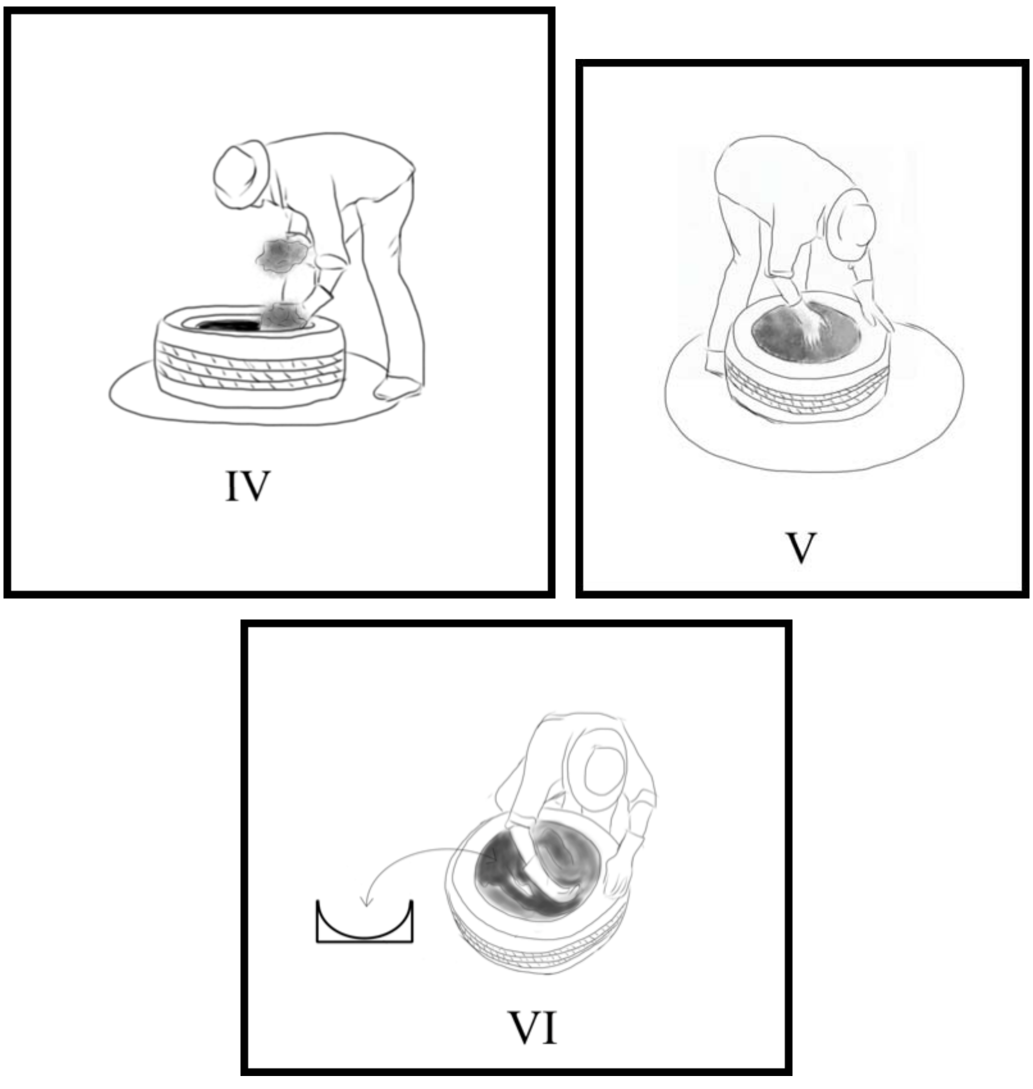

Figure 30. Hemispherical bottom formation

Continue stacking and packing the tires with FRBM one at a time until the minimum height of approximately 3 ft. (1 m) is reached as per the process described in Figure 30 and shown in Figure 31. Once complete, the tires will then be encased in a thin layer of FRBM in a manner similar to plastering or applying stucco to a wall.

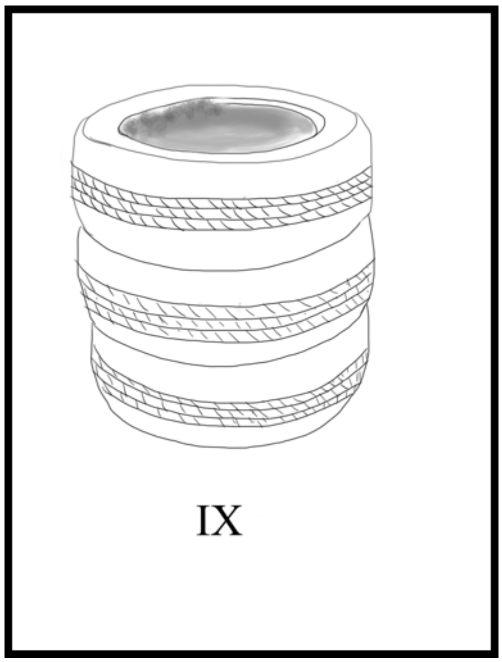

Figure 31. Stacked tires without exterior finish

2. Basket Reinforced ERW-CP

When not using whole tires, vertical stabilizers are used to provide the structural support. The vertical stabilizers can be driven directly into the ground eight to 12" (25.4 cm) away from a suitable 20"–24" (50–60 cm) I.D. form. If driven into the ground, an above ground height of approximately 3' ft. (1 m) high must be maintained.

Alternatively, a base layer of FRBM can be used to "set" the vertical stabilizers in position. A base layer of FRBM several inches deep, 8"–10" (25.4 cm) wide, should be placed around a suitable 20"–24" (50.8 cm) I.D. form. Once the base layer has firmed up slightly, the vertical stabilizers are placed vertically into the FRBM at the outer most edge.

Once the vertical stabilizers are "set," the horizontal stabilizer material is woven into the vertical stabilizers to form a basket as shown in Figure 32.

Figure 32. Base prep and vertical reinforcement placement

FRBM is then placed between the I.D. form and the basket to build up the cylindrical wall of the ERW-CP as shown in Figure 33.

Figure 33. Filling a tire basket with FRBM

Once the FRBM wall has been placed, set two security eyelets 180 degrees apart within the top two inches (6 cm) of the ERW-CP rim, as shown in Figure 34. A matching set of security eyelets will be set into the ERW-CP lid to allow the ERW-CP to be secured.

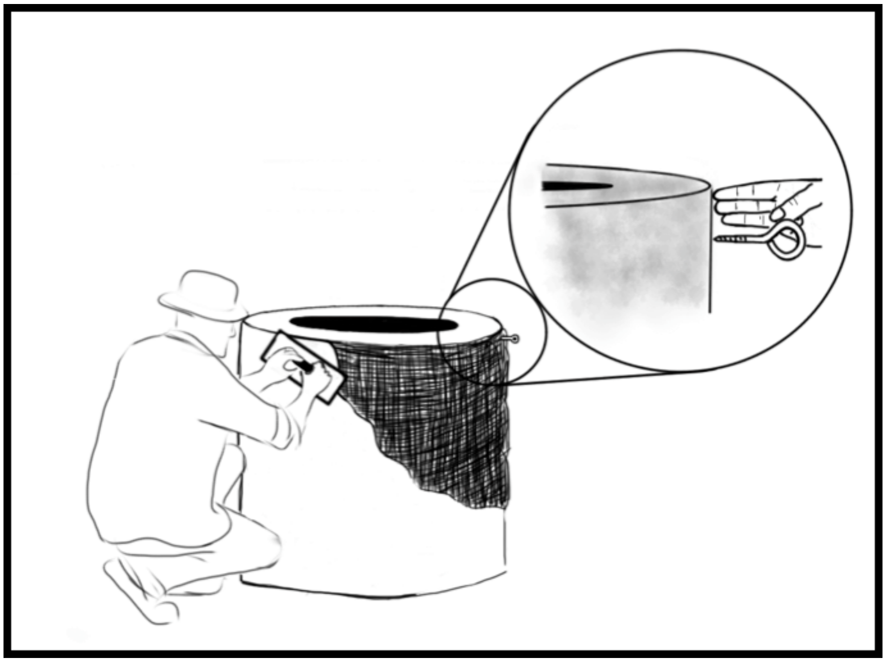

Figure 34. Setting security eyelets

After a few hours, the I.D. form can be removed and work can begin on the internal hemispheric bottom of the ERW-CP. Once the I.D. form is removed, the internal hemispherical base must be formed. The internal hemispherical base provides the proper shape and mass for the base of the structure to redirect the thermal effects and blast wave of a detonation.

A base layer of FRBM is placed directly on the ground inside the ERW-CP wall approximately 3” thick. The FRBM is then formed and finished smooth by hand to form the I.D. hemisphere in the same manner as the tire reinforced ERW-CP, as shown in Figure 35. Completing this process immediately after the I.D. form is removed allows the core and the hemispherical base to set and cure together creating a bonded unit.

Figure 35. Finished internal hemispherical base

3. ERW-CP Lid

The lid of the ERW-CP is constructed of roughly 3” of the same FRBM as the base. The 20”–24” (50.8 cm) I.D. hole in the middle of the lid will match the I.D. of the base to allow the detonation to vent directly up and out of the ERW-CP away from the surrounding area, as shown in Figure 36. Any available reinforcements capable of spanning the venting hole in the lid will be set into the FRBM flush with the ground.

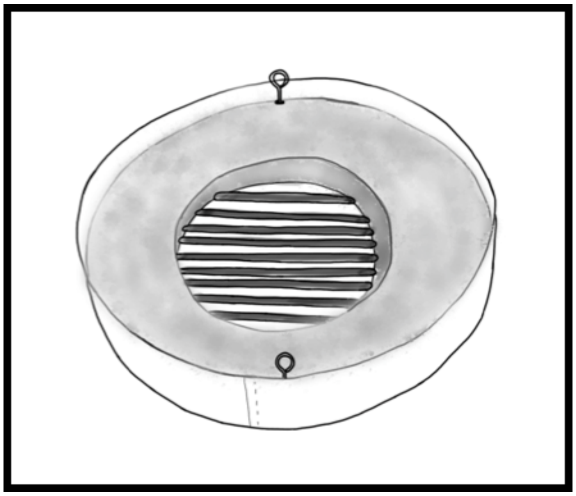

Figure 36. ERW-CP lid construction with flexible form

4. External Finish

Once the core of the ERW-CP has set, an external finish must be applied. The external finish serves several purposes. First, it gives the ERW-CP a permanent, secure, impenetrable look. Second, although thin, it provides yet another layer of FRBM to mitigate the effects of a detonation. Third, it provides a smooth maintainable surface to paint, which protects the ERW and the structural integrity of the ERW-CP from the elements. Lastly, it provides a finished surface to paint on or adhere to for international symbols or labels regarding explosive hazards or mines.

The finish layer of FRBM should be of the proper consistency to stick to the walls of the exterior of the ERW-CP core. It may be difficult to adhere the exterior finish layer to tire ERW-CPs. If available, burlap fabric, coffee/rice sacks, or a similar mesh may be wrapped around the ERW-CP core to provide a more suitable bonding surface. See Figure 37.

Figure 37. External FRBM Finish applied to mesh

Likewise, once the ERW-CP lid is set and cured, it is turned over and a thin external finish is applied covering the venting hole, which is easily accomplished by placing any very thin material or fabric over the lid vent hole and applying exterior finishing material over the whole lid that is done for the same reasons the external finish is applied to the base. See Figure 38.

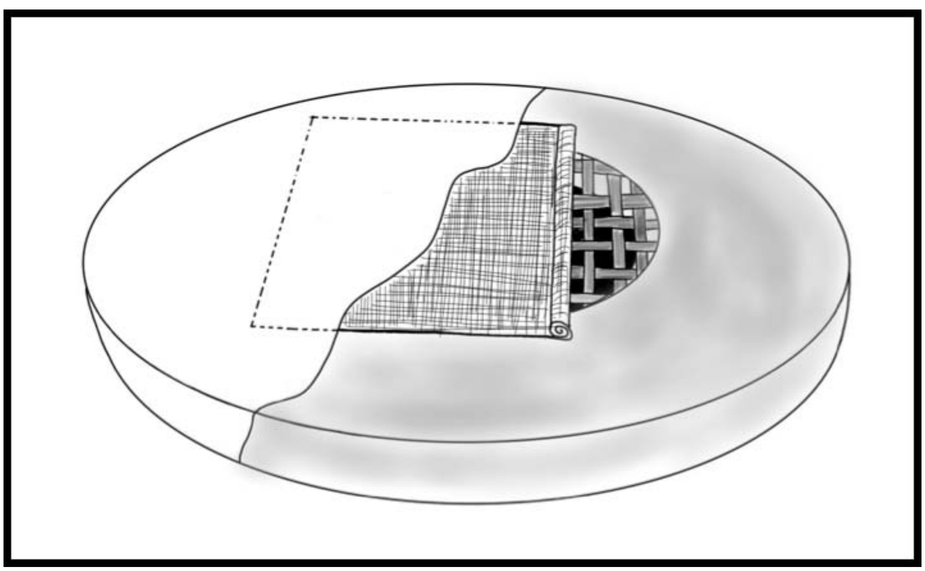

Figure 38. External FRBM Finish applied to mesh on lid

It is recommended that ERW-CPs be constructed well in advance of the discovery of ERW. As with most cement-based products, the longer the structure is allowed to cure, the stronger it becomes. However, if required, the ERW-CP may be used after a 24-hour curing period. In the case of immediate usage, it is recommended that ERW-CPs not be used or painted until signs of moisture are no longer visible. This time frame will depend on weather conditions and the amount of water used in the FRBM mix. Figure 39 displays an example of ERW placement in ERW-CP.

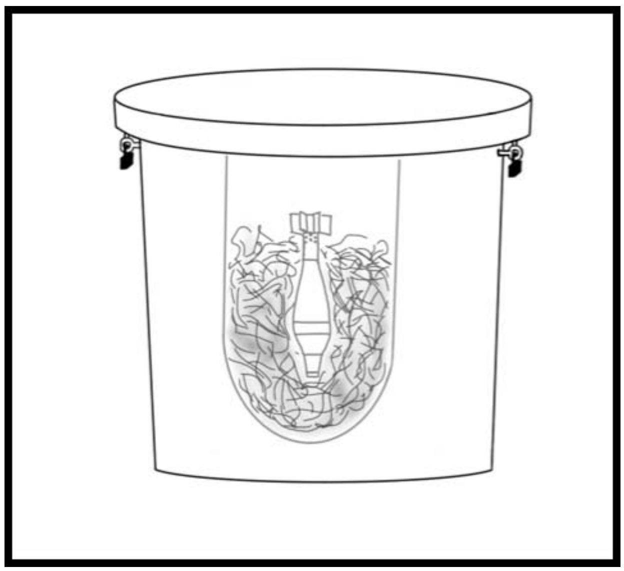

Figure 39. Example of ERW placement in ERW-CP

D. SYSTEM RETIREMENT AND MATERIAL RECYCLING/DISPOSAL

If the construction process was followed properly and proper maintenance preformed, such as regular painting, the ERW-CP should have a considerable life span. As signs of weathering and degradation appear, the structure should be replaced.

However, it is anticipated that in the spirit of safety, and recognizing the benefits of the ERW-CP explosive mitigation, qualified disposal personnel may chose to use the ERW-CP as a disposal platform. This option is not only acceptable but highly

encouraged, as long as the customary explosive disposal safety measures are followed. Once a disposal operation has been conducted within an ERW-CP, the structure must be replaced.

All material used in the construction of the ERW-CP should be locally sourced. Therefore, all material should be easily disposed of or repurposed. Natural fibers and cements can simply be left to decompose naturally or repurposed. In the case of tire reinforced ERW-CPs, if the structural integrity of the tire and FRBM is sound, it may be reused by simply restacking and refinishing the interior and exterior. However, the lid will need to be completely replaced. The same applies in the case of tire basket reinforced ERW-CPs. If the tire tread strips are still in good condition, they can be reused in the newly constructed ERW-CP.

APPENDIX B. DETAILS OF ERW-CP TEST AND EVALUATION

A. TESTING FACILITIES

1. Lawrence Livermore National Laboratories' High Explosives Application Facility

To test the ERW-CP design, Lawrence Livermore National Laboratories High Explosive Application Facility (HEAF) graciously volunteered the use of their facility. The ERW-CP test platforms and structures were constructed off site and transported to HEAF's large spherical tank, Figure 40.

> The High Explosives Application Facility (HEAF) has seven fully contained firing tanks for testing explosive quantities from less than a gram up to 10 kilograms (22 pounds) net explosive weight. These tanks provide a way to conduct explosive experiments indoors under well-controlled conditions with elaborate dynamic diagnostics. HEAF is equipped with extensive, high-fidelity, high-speed diagnostic capabilities including x-ray radiography, x-ray tomography, high-speed photography,
>
> Many types of tests are executed in these tanks including cylinder test for detonation performance, blast tests for enhanced blast explosives including thermites and thermobarics, and the scaled thermal explosion (STEX) test to characterize the violence of thermal explosions due to physical containment coupled with elevated temperatures. HEAF was recently tasked by TSA and Homeland Security to investigate the threat of "improvised explosives", those that could be formulated by a terrorist using commercially available materials.[95]

[95] Lawrence Livermore National Laboratories, "LLNL's High Explosives Applications Facility," July 10, 2009, https://wci.llnl.gov/fac/heaf/activities_ops/tanks_gun.html.

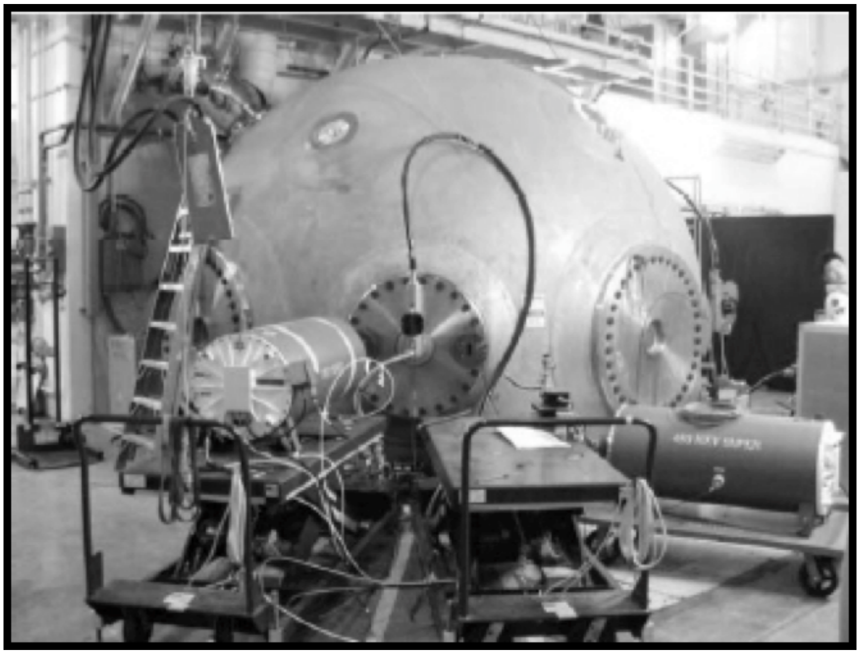

Figure 40. HEAF spherical tank

2. JIFX—Camp Roberts Range 18

A second series of tests were conducted under field conditions on Camp Roberts during the Naval Postgraduate School's Joint Field Interagency Exploration (JFIX) event. The explosive tests were supported by Camp Roberts Range Control and U.S. Army 217th EOD.

B. PREPARATION FOR TEST AND EVALUATION

1. Testing Platforms and Structures

The design requirements mandate that the structure be functional on a variety of surfaces, the most likely of which will be bare earth. However, the LLNL HEAF testing facilities do not allow for bare earth contact. To simulate bare earth, portable-testing platforms were constructed and filled with no less than 8" of compacted dirt. The ERW-CPs were then constructed on the test platforms, using the methods described in Appendix A, and transported to the testing facility. The test platforms were then placed on reinforced solid steel platforms to undergo the explosive tests. See Figure 41.

Figure 41. Testing Platform Set Up

For the JIFX field-testing the ERW-CP structures were constructed on Camp Roberts and transported to the Range 18 via flatbed truck. Range 18 allowed for the ERW-CPs to be placed directly on the ground for a realist scenario. Unfortunately, in both instances, the structural integrity of both test sets were somewhat compromised in transit, which resulted in hairline fractures and open cracks in all structures. However, due to the layered nature of the structural design, these cracks were deemed to have minimal effect on the tests. Since field versions are to be constructed in place, and used in place, the JIFX Camp Roberts testing became more conservative.

2. ERW Simulation Device

a. LLNL / HEAF

The characteristics of actual ERW vary greatly, which makes them an unreliable unit of measure to conduct tests. To simulate ERW in a controlled manner, many of the tests conducted on commercially available containment and mitigation

solutions use a base line of 1 lb. TNT equivalent, of black powder. Likewise, the ERW-CP test parameters will use a base line of 1 lb. TNT equivalent, of composition 4 (C-4) explosive. Of the tests conducted, the NEW averaged 456.5 g or 1 lb. 0 oz. with the addition of the PBX boosters.

Although the TNT equivalents are the same compared to the COTS mitigation devices, C-4 has a higher brisance than black powder. Brisance is the shattering or crushing effect of a high explosive as a result of the speed at which the explosive reaction occurs. In laymen's terms, this phenomenon makes C-4 a more powerful explosive than black powder, which makes the ERW-CP tests more robust than the industry standard.

Much like the sandbag mitigation technique, the test parameters were designed assuming that any ERW with a diameter greater than 6" contains more than 1 lb. net explosive weight (NEW) and will exceed the mitigation capabilities of the ERW-CP. To simulate an ERW fragmentation pattern, the 1 lb. explosive charge is placed in a scored, caped, galvanized metal sleeve (caped pipe nipple). See Figure 42. These limits and test parameters are conducive to similar or greater than tests conducted on commercially available containment and mitigation devices. Simulating a fragmentation producing ordnance item containing 1 lb. of explosive falls within the parameters of EOD disposal operation calculations and considerations for a single item under 6" in diameter.

Figure 42. ERW simulator (pipe-bomb) and two lb. shot

b. JIFX

Based on the ERW-CPs' performance during the LLNL/HEAF tests. the test parameters were expanded. The NEW of the ERW simulation devices used in the field tests was increased from 1 lb. TNT equivalent to 1 lb. 4 oz. C-4 or 566.99 g, which is the standard M-112 demolition charge used by the DoD. This increase may not seem significant; however, due to the nature of high explosives, any increase in NEW should be considered significant. Additionally, this configuration very closely resembles the EOD shot set-up of a single item ERW disposal operation.

C. TEST PERFORMANCE, DATA COLLECTION AND ANALYSIS

The controlled environment and instruments used to conduct the LLNL/HEAF explosive tests were well beyond the requirements needed to provide an ERW-CP proof of concept. Due to the unpredictable nature of variations in ERW-CP quality, a broad scope of ERW-CP building materials were used in construction. As a result, broad scopes of performance parameters were expected. LLNL/HEAF personnel conducted all explosives preparation and firing, test equipment setup, and data collection. LLNL/HEAF personnel and the design team conducted analysis of the data.

1. LLNL/HEAF Test Parameters and Setup

a. Frag

Goal: Completely contain or defeat of all primary fragmentation.

Verification: Any fragmentation penetration could be observed via Phantom high-speed cameras. Verification was accomplished by the lack of visible signs of fragmentation penetration on the interior wall of the spherical tank, and the lack of fragmentation outside of the ERW-CP structural remains.

b. Blast

Goal: The desired K-24 blast mitigation level is the best-case scenario. Blast wave mitigation levels of K-50 are considered a successful test. As per DoD Ammunition and Explosives Safety Standards Manual (6055.9-STD), personnel protection must limit incident blast overpressure to 2.3 psi (15.9 kPa).[96]

Verification: Blast wave mitigation was observed via PCB Piezotronic 137A21 pressure sensors at a distance approximately 36" from the outside diameter of the ERW-CP. The two sensors were placed at mid-structure and base/lid seam level.

c. Thermal

Goal: Thermal effects are far less of a concern than fragmentation and blast. It is believed that the combination of distance and structural shielding provided by the ERW-CP will sufficiently mitigate all thermal effects. As per DoD Ammunition and Explosives Safety Standards Manual (6055.9-STD), personnel protection must limit thermal fluxes to 0.3 calories per square centimeter per second [12.56 kilowatts per square meter].

Verification: Thermal mitigation was observed via internal spherical tank thermometers and Phantom high-speed cameras.

[96] Department of Defense, Under Secretary of Defense for Acquisition, Technology & Logistics, "DoD Ammunition and Explosives Safety Standards 6055.9-STD," 42.

2. LLNL HEAF Testing Results

The initial testing conducted on various ERW-CP designs was deemed a success. All observable test and design parameters were met. No primary fragmentation penetrated the exterior of the ERW-CPs. Due to the size of the spherical test chamber 16 (16 ft. 4.8 m) mitigation of secondary fragmentation mitigation was not confirmed. However, based on the projected trajectory of ERW-CP exterior fragments viewed in the high-speed video, it was determined that the majority of fragments would have impacted the ground within 24 ft.

Blast wave mitigation was confirmed by observing peak pressure waves well below 2.3 psi taken at two positions averaging 36” from the ERW-CP at the base and lid levels, which is very encouraging as the 2.3 psi limitation is for a minimum distance of approx. 30 ft. from detonation point. The outlier in the test set, shot four (S-C-W-NF), was a result of a non-fragmentation producing explosive charge. In the absence of the pipe, the explosive reaction was allowed to expand uninhibited. The noticeable psi increase in shot six (S-C-B-F) was the result of doubling the explosive weight to approximately 2 lbs.

However, as observed, the increase in the measured blast wave in both instances was less 1.1 psi or less than half of the 2.3 psi blast wave threshold. With the exception of shot four, the remainder of the shots measured below 0.5 psi, which is well below K-50 at 0.89 psi.

Four of the shots averaged 0.34 psi, which is within the range of K-70 to K-111. In the K-70 to K-111 range, individuals will experience fullness in the ear or ringing/roaring (tinnitus) and some may experience mild vertigo.[97] To reiterate, these measurements were taken at two points, 36” from the surface of the ERW-CP and represent peak psi at the sensors. See Figure 43.

[97] Naval Explosive Ordnance Disposal Technology Division, “Protection of Personnel and Property,” 45.

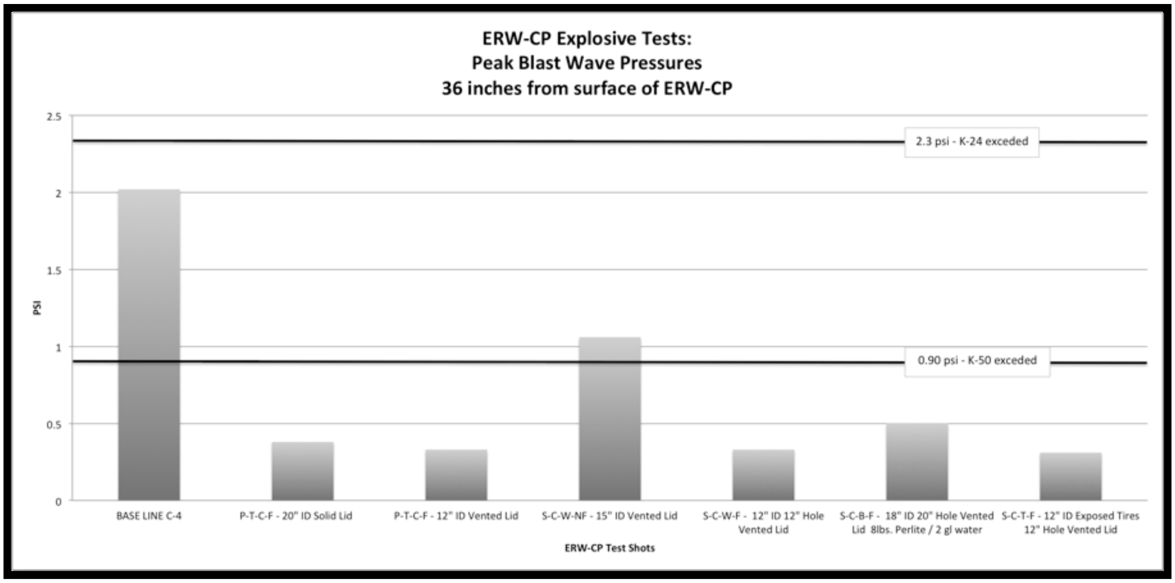

Figure 43. ERW-CP Explosive Testing Blast Wave Mitigation

Thermal effect mitigation was confirmed by observing the energy deflection via the Phantom high-speed cameras and a temperature increase of less than three degrees on average inside the spherical test chamber. The outlier in the test set (S-C-W-NF) was a result of a non-fragmentation producing explosive charge. In the absence of the pipe, the explosive reaction was allowed to expand uninhibited. The slight variation in shot (S-C-B-F) was due to a doubling of explosive weight to approximately 2 lbs. However, as observed, the increase in temperature for shot (S-C-B-F) was less than three degrees and can be considered negligible. See Figure 44.

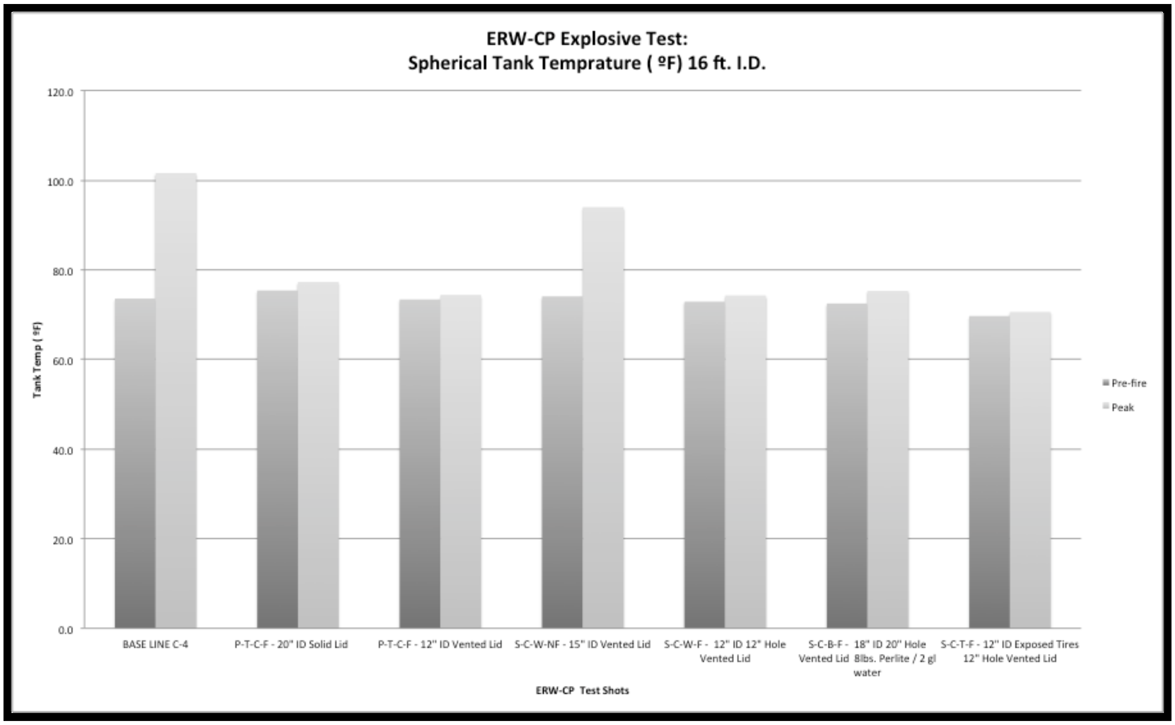

Figure 44. ERW-CP Explosive Testing Blast Wave Mitigation

3. JIFX Field Test Parameters and Setup

The desired test results of the JIFX field tests are the same as the LLNL/HEAF tests. However, due to field conditions, the only method of verification was observation.

a. Frag

Goal: Completely contain or defeat of all primary fragmentation. Mitigate the effects of secondary fragmentation having an impact energy of 58 ft-lb. or greater to a distance of 24 ft. and eliminate secondary fragmentation to a distance of 50 ft.

Verification: Any primary fragmentation penetration could be observed via high-definition cameras, as well as observation of secondary fragmentation. A 24 ft. radius circle was placed on the ground around each ERW-CP. Additionally, a test dummy was placed 50 ft. from all ERW-CPs.

b. Blast

Goal: The desired K-24 blast mitigation level is the best-case scenario. Blast wave mitigation levels of K-50 are considered a successful test. As per DoD Ammunition and Explosives Safety Standards Manual (6055.9-STD), personnel protection must limit incident blast overpressure to 2.3 psi (15.9 kPa).[98]

Verification: Blast overpressure/wave mitigation was observed via PCB Piezotronic 137A21 pressure sensors at a distance approximately 40” to 35” from the outside diameter of the ERW-CP. The two sensors were placed at mid-structure and base/lid seam level.

c. Thermal

Goal: Thermal effects are far less of a concern than fragmentation and blast. It is believed that the combination of distance and structural shielding provided by the ERW-CP will sufficiently mitigate all thermal effects. As per DoD Ammunition and Explosives Safety Standards Manual (6055.9-STD), personnel protection must limit thermal fluxes to 0.3 calories per square centimeter per second [12.56 kilowatts per square meter].

Verification: Thermal mitigation was observed via internal spherical tank thermometers and Phantom high-speed cameras.

4. JIFX Field Testing Results

The ERW-CP field-testing went extremely well. After reviewing the LLNL/HEAF explosive testing data, the team was confident that any fragments resulting from the fracturing of the ERW-CP exterior did not have the required force to be considered secondary fragmentation. However, it was not until the field test that it could be confirmed. As expected, even with the increase in simulated ERW explosive weight, no primary fragmentation escaped the ERW-CP. As with the LLNL/HEAF tests, the exterior of the ERW-CP exterior fragmented from the main structure. However, the

[98] Department of Defense, Under Secretary of Defense for Acquisition, Technology & Logistics, “DoD Ammunition and Explosives Safety Standards 6055.9-STD, 42.

majority of the fractured ERW-CP exterior came to rest well within 24 ft. of ground zero. A few ERW fragments landed within or just outside of the 24 ft. radius but came to rest within a few feet after landing. No ERW-CP exterior fragments reached the 50 ft. radius limit.

Blast wave mitigation was observed via high-definition cameras placed next to the test dummy 50 ft. from the outside diameter of the ERW-CP. Although no pressure sensors were available, blast wave mitigation was visible via high definition video. As both LLNL/HEAF and the JIFX ERW-CP structures preformed similarly, it can be assumed that the same blast wave mitigation level of > 2.3 psi was maintained.

Thermal mitigation was observed in the same manner as described above. Via high-definition cameras, all thermal effects were completely redirected up. See photo series in Figure 45.

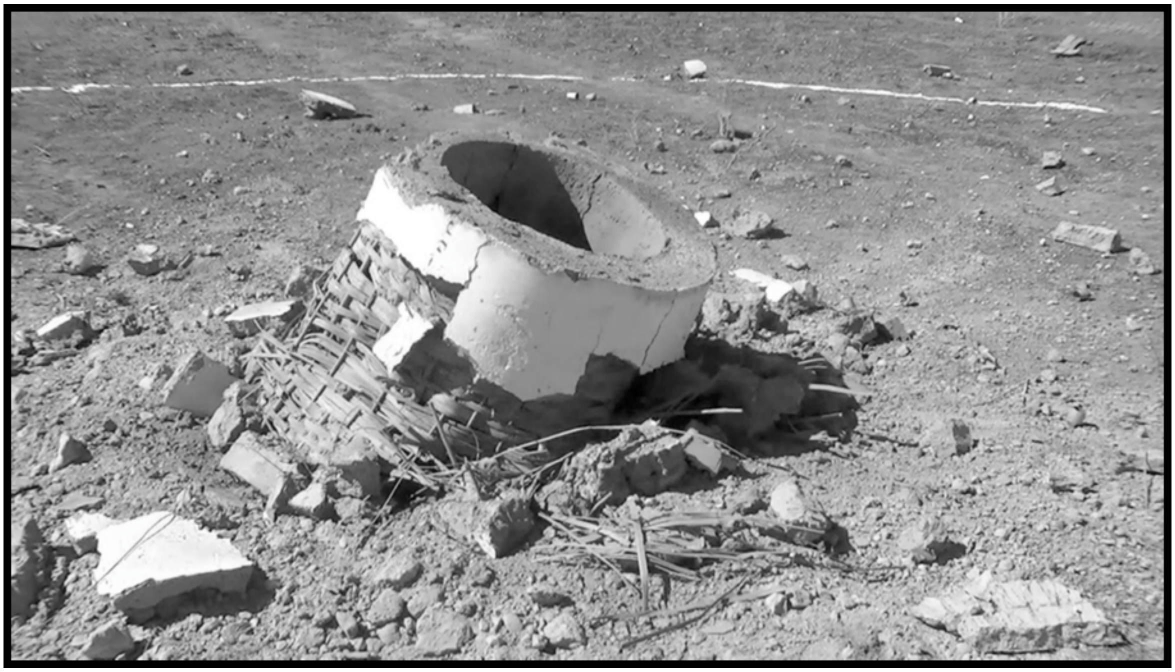

Figure 45. Successful bamboo reinforced ERW-CP field test photo series

5. Summary

The ERW-CP design concept is ready to field. The preliminary tests conducted verified all ERW-CP design parameters were met or exceeded.

a. Frag

All primary fragmentation was contained or defeated. Most secondary fragmentation having an impact energy of 58 ft-lb. or greater was mitigated to a distance of 24 ft. while all secondary fragmentation was eliminated at a distance of 50 ft. Additionally, the test dummy placed at 50 ft. from all ERW-CPs received no damage, and remained undisturbed throughout the entire test series.

b. Blast

The K-24 blast overpressure mitigation level (>2.3 psi 15.9 kPa)[99] was verified during the LLNL/HEAF tests by two PCB Piezotronic 137A21 pressure sensors

[99] Department of Defense, Under Secretary of Defense for Acquisition, Technology & Logistics, "DoD Ammunition and Explosives Safety Standards 6055.9-STD, 42.

at a distance approximately 40” to 35” from the outside diameter of the ERW-CP. A K-50 (> 0.89 psi) blast overpressure mitigation level was verified on five of the six shots, including the 2 lbs. shot. Mitigation of the blast wave during the JIFX testing was verified by observation using high definition cameras and a test dummy.

c. Thermal

All thermal effects were mitigated through structural shielding provided by the ERW-CPs in both test series. As per DoD Ammunition and Explosives Safety Standards Manual (6055.9-STD), personnel protection must limit thermal fluxes to 0.3 calories per square centimeter per second [12.56 kilowatts per square meter]. Verification was accomplished via internal thermometers in the LLNL/HEAF spherical tank. During the JIFX field tests, thermal mitigation was verified by observing the actual redirection of explosive energy via high definition cameras.

d. Conclusion

As with all designs, further testing and development is highly encouraged. However, due to the variety of construction materials the ERW-CP is designed to use. and the environments to which the ERW-CP is intended to be deployed, further development should not be geared toward any one standard. In keeping with the spirit of the project, the broadest spectrum of design dissemination and construction methodology should be maintained.

The ERW-CP design described and tested in this study implements a simple, scalable, design and construction methodology utilizing locally sourced, sustainable, and repurposed materials. Through a train the trainer approach, a basic “How to Manual,” Appendix A, accompanied by a completely pictographic “How to Poster,” are presented as the preferred method of knowledge dissemination. Programs, such as Humanitarian Demining, Foreign Internal Defense and Village Stability Operations, along side International Aid efforts, are cited as examples of appropriate levels of disseminating the ERW-CP concept to assist in strategic partner capacity building, post conflict stabilization efforts, and the global ERW, Mine/UXO education, management, and disposal efforts.

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